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AN INTERPRETATION OF BIOLOGY

by

HENRY COLLIER
Musgrave Research Student in Zoology
at Queen's University, Belfast

with a Prefatory Note by
JULIAN S. HUXLEY

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TO

PATIENCE

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PREFATORY NOTE

by JULIAN S. HUXLEY

THE RELATIONS between science and society are extremely important. There is no such thing as pure science pursuing its ideal course in a social vacuum, and no sharp or essential distinction between pure and applied science, though these terms still have a useful practical connotation. On the other hand, the cruder forms of the doctrine of economic determinism do not apply to science any more than they do to other human activities. Science is a social function, but it also has its own momentum and is an activity which can be pursued for its own sake.

Mr. Collier here sets forth some of the essential facts about biology and its relation to social life in a pithy and illuminating manner. We should be especially grateful to him for pointing out the limitations of biological explanations for human activities. Man is such a peculiar organism that his behaviour needs a special set of categories for its description, over and above those of biology. None the less, biological categories are basic for human affairs, and it is useful to have them so clearly set forth.

PART I

The Reason for Biology

CHAPTER I

THE MEANING OF THE WORD

MODERN MAN has created the science of biology. Frequently, like a precocious child, the offspring turns and scrutinises its parent. " What meaning," it asks, " have human beings for biology ? " But the parent is also entitled to a point of view. What meaning has biology for human beings ? Why are they making it ; what does it tell them ; what use is it ?

Biology speaks in a learned and often a dead language ; it is a large and indigestible subject ; but it is not remote or mysterious. Birth, inheritance, growth, food, health, sex, parasites, gardening, farming, fishing, baking, brewing, and preserving food are part of the texture of human life. Biological science embraces all these matters, dealing with them in a practical and searching way.

In studying these questions, biology uses a practical method of inquiry, by making facts always the test of theories. If an observation contradicts an idea, it is the observation which is taken note of, and it is, or ought to be, the idea which is abandoned. Because biology is built up on facts verified by repeated tests, its findings enable one to forecast what will happen and to act accordingly. The knowledge that blood-poisoning is due to minute living beings, which get into a wound and live there, enables the surgeon to take precautions against it. The microbes might be introduced into the wound on his knives. By heating the instruments before the operation, he kills the microbes and eliminates the danger.

CHAPTER II

THE USES OF EXACT KNOWLEDGE

EXACT KNOWLEDGE enables us to forecast what will happen. Knowledge is therefore a first step to useful action. The closer our understanding of matters of fact, the more accurate can be our forecasts, and the more useful the action we can take. The prevention and cure of the disease of rickets serves as an instance of the powers of control which a knowledge of the facts provides.

The history of rickets has been recently described by Dr. L. J. Harris.[1] The disease was an appalling feature of nineteenth-century towns. In 1868, one-third of the children of London were estimated to suffer from severe rickets. To realise this fully you must look at the bowed and twisted, rickety skeletons in medical museums. When its cause was unknown little action could be taken against rickets. But, during the second half of the last century, there were some doctors who realised that cod-liver oil was a cure for rickets. At the same time there were other prominent doctors who scoffed at the idea. It was not really until after the war that more exact discoveries showed the true value of cod-liver oil. It was then discovered that rickets is entirely due to the lack of certain substances in the food, sometimes to an insufficiency of minute quantities of only one substance, called *Vitamin D*. This substance is present in cod-liver oil. In 1932, pure Vitamin D was separated as a single substance. " One ounce of the vitamin," Harris calculates, " is . . . enough to provide a daily dose for over 1,000,000 children." The result of this sharp increase in precise knowledge, applied with a moderate amount of purpose, is a great diminution in the number of cases of severe rickets.

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[1] *Vitamins in Theory and Practice*, L. J. Harris. Cambridge University Press.

Not only knowledge but social purpose is necessary to eliminate the disease. The obvious cases of rickets attract the doctors' attention and receive treatment, but the disease has by no means disappeared. Rickets figures to a noticeable extent in the reports of school medical officers in 1936. A really close examination of five-year-old, London elementary-school children in 1928 showed that 87 per cent had had rickets to some extent, while 40 per cent had had it quite noticeably. Yet all these children were born in 1923, a year after the discovery of Vitamin D.

The case of rickets shows the point of knowing the conditions which living beings require in order to reach their normal state of well-being. But knowledge and technical resources can also be used to change present forms of things, and to make new forms. Chemists have created many substances which have never been known to exist before. Biology can already transform some living things. The head of a growing fish, for example, can be enlarged out of proportion to the rest of its body by exposing it to the drug *atropin*. Differences between parent and offspring can be artificially engendered in flowers and in animals. These are only the first steps. As the control of the methods becomes closer, it should be possible to improve domestic plants and animals, and to make new forms of living beings.

CHAPTER III

DISCOVERING THE FACTS

SCIENTIFIC RESEARCH is the technique of learning how the world is working. Continual practice has developed a group of methods for the purpose of discovery. The technique is nothing more than a more exact, and more extended, version of what anyone does when he wants to find out something for himself. To describe it briefly, it is the process of discovering the facts, making conclusions in your mind that cover them, and testing the conclusions with other facts. Suppose the electric light in your room fails. You decide from other experiences that either the bulb or the fuse has gone. To find out which it is, you must test parts of the circuit separately. You turn on other lights in the house. If these bulbs light up you know the defect is confined to one room. You conclude it is the bulb and try a new bulb in place of the doubtful one. If it lights up you have solved the problem. Here, in short, you are making conclusions from facts, and then testing the conclusions in practice. In the earlier stages of a science the discovery of facts occupies the main attention of research. Later, when far-reaching conclusions have been made from the facts, these are used to find new facts and theories.

A conclusion which is derived from a good many individual cases is extremely useful because it may apply in many other cases. For instance, though I know very little about electricity, I find making up electrical circuits simplified by the use of Ohm's law, which tells me how current, resistance, and electrical potential in any circuit are related to each other. If scientific results are to be used for a variety of purposes, the easiest method is to investigate a simple case, and to work out from this the general principles of its action. These principles may then be applied to any number of other cases of the same type.

The search for principles leads science, therefore, to look at natural events which in themselves are not of the slightest use to anybody. For example, very many biologists have been busy examining every aspect of the breeding and inheritance of a single type of fly—the fruit-fly. Though inheritance in the fruit-fly is of no great importance in itself, the mechanism by which it works is the same as that in plants and animals of agriculture. The fly breeds very quickly, is easy to keep alive in a laboratory, and is easy to handle. It is therefore most economical to tackle questions in the fruit-fly, the answers to which will subsequently be used to improve crops and livestock. Research gradually makes a set of principles describing how living beings work. This set might be compared with a Bradshaw time-table, which may be consulted whenever and wherever necessary. Though much of biology is never used, much touches human practice at different points. A distinction between " pure " and " applied " biology is of no great use, because the science is one whole.

Science to-day is thus apt to deal with both general principles and with particular practical questions. The emergence of modern biology, proceeding at a slowly accelerated pace from the mid-fifteenth century to about 1860, and then bursting into a run, was all along connected with practical issues. This connection is clear, for example, in the field of the systematic classification of living forms, which develop in relation to a number of questions. What plants have medical or poisonous properties, and how can they be distinguished ? What are the plant and animal resources of newly discovered lands ? What are the depths of the ocean like, and how far are they suitable for the laying of telegraphic cables ? What are the food, movements, and breeding habits of the shoals of edible sea-fish ? What are the creatures that prey on and damage man, crops, and livestock ; and what are their enemies ? In helping to answer these questions a systematic classification of living forms is a preliminary. Once this has been started, it continues under its own steam, collecting, scrutinising, and allocating to its proper group every available creature. Studies which arise out of practical questions themselves raise further problems. In answering its own problems, a branch of knowledge develops along its particular line.

We have seen how the need to discover the principles leads scientists into regions of apparently "pure" science. We shall see how, also, the technical requirements for discovery make science dependent on industry and transport. Discovery requires certain powers of dealing with nature. The first is the power to see, feel, or receive an indication of what is happening. We may be able to use our own senses directly, or we may have to use an indirect method to tell what is happening. You can test an acid by its sour taste, or you can use a dye which changes colour in the presence of acid.

The second power which is usually necessary for getting to know about nature is that of separating one part of nature from another. The world is various, complex, and changing. Even most of the simple forms of biological research involve separating plants or animals from their natural surroundings. For instance, the collection of different plants and the comparison of their shapes involves uprooting them, taking them to pieces, and describing the distinctive features of their flowers, leaves, and stems. A pulled plant is different from a plant in the field because it is dead or dying. Even a living plant in a flower-pot is different from a plant in the fields. It will have different characteristics of size, shape, etc., because it is not subject to the competition of its fellows, nor to the same soil conditions as they.

Isolation creates a possibility of error. For the purpose of research it is convenient to distinguish various parts of nature one from another. Some of the famous mistakes in the history of biology have been made in forgetting that these separated parts can change and can affect one another. The idea that the races of animals and plants were fixed for all time was a mistake of this kind. Though an early biologist like Ray, in the seventeenth century, had thought that the races of living beings might be transformed, Linnæus, in the eighteenth century, firmly clamped on to the study of classification the theory that all the races of living beings had been fixed for ever. This idea was not thoroughly overturned until after the publication of Darwin's *Origin of Species* in 1859.

Not only does the need of powers of isolation and description introduce the possibility of mistakes; it also limits the advance of biology. Unless there are means of isolating and describing an event in nature, it cannot be studied. Microbes could not be studied far without the microscope and without the powers of cultivating each kind of microbe separately in glass vessels. Still smaller bodies than microbes require even more complicated technical methods, like the use of X-rays, to investigate their nature. Even anatomy, the study of the shapes and arrangement of the parts of the body, requires knives and tweezers to separate the organs from one another. The collection of different kinds of plants and animals requires at least the means of transport and centrally placed museums. In short, the development of biology, itself depending on the discovery of facts, waits on the development of the technical means for research. It depends, therefore, on the growth of physics, chemistry, engineering, industry, and transport.

CHAPTER IV

WHY RESEARCH?

ONE OF THE MOST STRIKING THINGS about biological techniques is their exactingness. They demand trained and interested men. In apparatus on the large scale, they require ships, museums, gardens, libraries, and laboratories. On a smaller scale, they need glass-ware, chemicals, water and electrical supply, knives, microscopes, cinematographs, and complex instruments of various sorts for measurement and record.

This means that biology, like all science, requires social as well as individual effort. It would be impossible for a smallholder, depending on the soil for his livelihood, to carry out far-reaching researches on the growth of his crops. He would not have the training to plan his researches, nor the time to make the necessary observations; he could not spare the ground space for trials to be made, nor afford the requisite chemicals or other materials.

Biology is doubly co-operative. First, it is a traditional growth, and past generations are drawn into co-operation with present generations in any piece of research. Each major step forward is the result of hundreds of observations and ideas. Secondly, in biological research the results of other scientific and industrial advances are made use of. The element *phosphorus* can now be turned into a state in which it radiates energy. By feeding a rat with radio-active phosphorus, the movements of the element inside its body can be mapped out. Again, the development of wireless has given the biologist the means of " listening in " to the activities of brains and nerves.

What is the exact connection between the development of biology and the society in which it grows? This has not yet been analysed in all its complexities, but it appears to follow the lines suggested in the last chapter. Biology builds a whole picture which bears on practice at many points. In general it can be seen that the growth of science has been part and parcel of the growth of industrial and agricultural production during the past five hundred, and especially during the last hundred, years. In this growth biology has both given and taken.

Again and again use has been made of the advances of chemistry, physics, and industry. We saw this happening in the cases of phophorus and wireless. It happened while navigation, the making of precision machinery, photography, and other techniques developed, and, above all, while social wealth accumulated. Biology has always depended on the release of men from commodity production for training and experiment. During recent centuries, increasing numbers of these men have been supported in academical positions, as teachers or curators of museums and botanic gardens. Rising numbers of scientific workers are supported by special grants and posts for research. I do not know the exact numbers of research workers in the different branches of science in England at present, but the greatest sums of money are expended in military research and in the various types of industrial research: considerably smaller sums are spent on the biological sciences, like agriculture, food preservation, and medicine. During the history of biology, the proportion of amateur to professional scientists has been declining; but there have been some very famous amateur biologists. At least two—Hales and Mendel—have been clergymen. Some, like Buffon and Sir Joseph Banks, have had private means; some biologists have just scraped along somehow; but serious advances were made by those with a good deal of leisure for their studies.

Society in return has benefited from biological research with inventions like chemical fertilisers, cultivated rubber, wheat that ripens during a northern summer, chilled meat, and with innumerable other advances. It would be hard to estimate the exact financial return on money invested in such research. The financial return of biological research as a whole would be a considerably lower percentage than that resulting from the two researches described below by Dr. Enid Charles: but it must be a very remarkable amount:

" For some twenty-five years past the commercial growing of cocoanut on one of the two large islands of the Fiji group has been made impossible by the ravages of a small Zygaenid moth. About seven years ago this moth threatened to invade the adjoining islands. Such an extension would have completely ruined the staple industry of the group, if unchecked. This would have entailed a loss of £400,000 per annum. By the introduction of a Tachinid fly which parasitises the cocoanut Zygaenid in Malaya the Fiji pest was so completely controlled that in three years' time it had become quite a rarity. The cost of this work was approximately £12,000. The late Mr. Frederick Muir estimated that his introduction of the Tachinid parasite of the weevil borer of sugar-cane into the Hawaiian Islands saved the cane-growers about a million pounds a year. He spent three years in searching for the parasite, eventually got from New Guinea. The total cost of the work was about £10,000."[1]

The average return on capital expended in these two cases works out at over 6,000 per cent per annum. It is stated that 20–25 per cent of the world's crops are every year destroyed by insects and other pests: this loss could be eliminated by biological research.

The work of the French chemist and biologist Pasteur provides a striking case of the intimate connection between biology and everyday needs. Pasteur was the originator of the process known as pasteurisation, which is most commonly applied to milk. In it, milk is heated to a temperature somewhat above blood-heat and kept hot for at least half an hour. By this means most of the microbes in the milk are destroyed. It then keeps better and is said to be healthier. Pasteur's work touched in most of its aspects the industrial and agricultural life of France, and now affects practices of brewing, milk treatment, food storage, surgery, public health, and many lesser known industrial techniques throughout the world. He was the man who solved the problems that the needs of the time were insistently setting. In the first stage of his biological work, which he carried out between 1856 and 1876, Pasteur investigated the manufacture of wine, beer, and vinegar, and the souring of milk. In the course of this work he established two principles. One is that all present-day animate beings are derived from other living creatures, and do not come into existence on their own. The other is that the fermentations which produce alcohol from sugar or starch, the souring of milk, and the turning of alcohol into vinegar are in each case carried out by living beings. Their bodies are minute in size and structurally simple. In the course of their natural modes of life they cause chemical transformations in the fluid in which they live. Milk is soured by microbes living in it. Other microbes have a similar effect on wine or beer. This souring of alcohol, which sometimes happens accidentally, is used in a controlled way in the manufacture of vinegar. The making of alcohol is due to various yeasts, which are larger bodies than the microbes, but nevertheless are very small in size. The yeast obtained from a baker or brewer contains a great many yeast bodies packed together.

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[1] *The Menace of Under-Population,* Enid Charles. Watts.

If yeasts or microbes are heated they die, and therefore heating is used as a means of preserving food and drink. By pasteurisation the souring of milk is slowed down, and the " vinegarisation " of wine or beer is prevented. Food is preserved by heating it and sealing it in microbe-proof tins. Most living bodies inside the tin are killed, while the few left alive are unable to be active, as there is no air available. Freezing is not used to kill, but to slow down the activities of microbes, by cutting off their water-supply in turning it into ice.

The next, and equally important, stage of Pasteur's work, was the application of his knowledge of the " illnesses," as he called them, of wine, beer, and milk to animal diseases. He showed that many diseases were due to microbes living in the body. He first demonstrated this in the case of silkworms, which suffered from severe plagues at that time. He later improved an ancient technique of combating microbes, which is one of the main methods used to-day. This consists of stimulating an animal's or a man's own powers of resistance to the infecting bodies. The stimulating, or vaccinating, method he first applied to the disease of anthrax, which was killing large numbers of French livestock. He ultimately used this method on man when, in 1885, he cured of rabies a child which had been bitten by a mad dog.

Methods of vaccination, town sanitation, tinning food, and of clean surgery, which had been in their infancy, were brought nearer maturity by the understanding of microbe action. Pasteur's work illustrates particularly clearly the fact which is not visible in some pieces of research: biological science as a whole is a basic part of modern agricultural and industrial production. His work is connected especially with questions of food preservation and of public health. Factory mass production demands labour armies, towns, and heavy consumption of foodstuffs. Food can only be stored and transported in bulk and health preserved in towns by a knowledge of how to destroy or to suppress the microbes that turn eatables bad and cause disease.

PART II

The Features of Living Material

CHAPTER V

THE TWO SPEEDS OF LIFE

LIFE IS ALWAYS MOVING. The biologist is never dealing with anything that is really still or unaltering, but always with developing processes. The processes with which he is concerned are of two main types, differing very greatly in the speed at which they go. There are the processes which move at about the same pace as that at which we pass our lives. These are the birth, life, and death of each of the animals and plants of the world. Besides these, there are the processes which are so slow that we can hardly ever catch a glimpse of their moving. They are the appearance, the flourishing, the change, and perhaps the decay of each different " race "of animals or plants, of which an individual is one member. The difference between the speeds of individual movement and of racial movement is thousands of times greater than the difference between the speeds of the second hand and the hour hand of a watch.

Looking at a bone coming, say, from the thigh of a rabbit, you might imagine it as a thing without past or future. You might observe how aptly the form suited the mechanical employment that was made of it; how the ball on one end fitted the socket of the adjoining hip-bone on which it moved. But the bone is not an unchanging thing; it has a past, or rather a double past, and a double future. It is part of the two processes described above. The first is the " personal " history of the bone, consisting of its coming into being within the growing rabbit's leg, its employment, and its final decay after that rabbit's death. The birth and use of the living bone would be measured in days, weeks, or years; it is a process which has a time-scale divided into days. The second kind of development in which the bone is involved is the coming into existence and the changes of the class of bone of which it is an example. The long-distant, fish-like ancestors of the rabbit had no limbs and no limb-bones. The development of rabbit thigh-bones as a class is a process which has a totally different time-scale, millions of years of which are equivalent to days in the growth of the individual bone.

In the case of some animals, the slow process of the coming into being of their " race " can be clearly followed for several million years. Their history is recorded in the series of bones that successive generations of their ancestors have left behind. Out of the small differences between these remains in each successive age, comes the birth of the modern animal. The horse is one animal the outline of whose history is fairly easy to trace. It can be followed for about the last 40–50 million years. The horse of the modern type has been in existence for about one million years; in the rest of the recorded story its ancestors increased their size and reduced the number of their toes. The most striking feature of the horse to-day is that it walks and runs upon a hoof, which is the enlarged nail of the enlarged third toe of the foot of the horse's ancestors. The earliest horse-like form had four toes in each fore-foot, and three toes in each hind-foot. The reduction and disappearance of these other toes can be traced in orderly steps from this earliest, or " dawn " horse, until all but one toe are practically gone. At the end of this sequence the horse of modern type comes into being.

The slow movement of life embraces its whole development, from its origin out of inanimate materials, perhaps 900 million years ago, through its division into the multifarious forms of to-day. The different speed of biological movements divides the science naturally into two parts, a study of races and a study of individuals. These two aspects of study are complementary, for the life of an individual is one step in the movement of a " race."

" Race " is rather a vague word. Some races of animals resemble each other more than others. Mice are more like each other than they are like rats; rats and mice together are more like each other than they are like cats; rats, mice, and cats are all far more like each other than any of them is like a flat-fish, and so on. For each degree of kinship biologists have a name. All house-mice in England belong to one *species*: this is called *Mus musculus*. All brown-rats belong to another species, but they have been placed in the same *genus* as the mouse, and they share with it the surname of *Mus*. The brown-rat species has been called *Mus decumanus*. Mice, rats, and cats are all warm-blooded and furry, and they suckle their young (a flat-fish has none of these qualities). They all belong to a larger group, or *class*, known as *mammals*. The classification of animals and plants which biology builds up proceeds thus into wider and wider circles. The brick of classification is the species; but even this is not immutable. At times species die out; sometimes new species are born out of the old.

Species and individuals lend themselves to be studied from various aspects. These aspects constitute the main branches of biological science. First it is necessary to divide the forms of life into carefully delineated species, and to establish the kinship of species. This is not an easy task, for the boundaries have to be made, and to decide on them demands constant comparisons between individual creatures. The process of classification involves the geography and history of species. Geographically, there are limits to the distribution of many groups. When a group gets isolated in one place, it develops along its own individual lines and becomes different from similar groups in other places. Historically, as we saw in the case of the horse, there is a slow change in species. In the successive fossil remains of past plants and animals, the boundaries between species are even vaguer than they are to-day. The study of the tangled problem of classification from all its aspects has led to the generalisation which has here been taken for granted: that modern forms of life have developed from fewer and simpler forms of the past. This process has been named *evolution*, or unrolling, but the term is not adequate to describe all the complexities of development.

The other half of biology is the study of individuals. Research can here be far more intimate than in the surveys which constitute the main part of the study of species. The life-cycle of many living beings is so short that we can interfere with it and observe the results of our own interference. This method gives a far more detailed understanding of events than merely surveying them can do. Individuals can be studied from three aspects. The first is the beginning, the growth, the mode of living, and the death of a single plant or animal. The second is how one generation is connected with another —how an individual reproduces his kind, and the mechanism by which his child comes to resemble its parent so closely. Thirdly, there is the question of how individuals impinge upon each other's lives. What is the whole connection between a flea and a man, or a horse and the grass? This is a vital part of human knowledge, for man lives by virtue of his dealings with certain creatures, like wheat, yeast, and sheep; and he is often killed through the activities of other living beings, like microbes or mosquitoes.

CHAPTER VI

AN ANIMAL TAKES SHAPE

LIVING BEINGS are quite concrete things, built of their own proper fabric, as much as a coat is made of cloth or a building of bricks. But the stuff which makes up plants and animals differs from brick and cloth because it is alive. Life, in fact, may be defined as the way this material carries on its existence.

Though living material once originated from inanimate matter, at the present time it always comes from other living material, and is never generated on its own. Microbes are not created by dirt, nor maggots by bad meat, any more than human beings are created by houses; but houses or meat or dirt are places where men or maggots or microbes thrive. From generation to generation a live fabric is passed on. When a new plant or animal comes into being, it always comes from some fragments of an already living plant or animal. A baby, or a puppy, for instance, is conceived by the joining together of two fragments of living material, one from each parent.

These are generalities. To see clearer how a body takes shape it is best to study the coming into being of a single animal. An animal whose personal history is one of the easiest to study is the frog, and so it happens that here the development, which so many living individuals undergo, is best understood.

A new frog starts from the union of two fragments of living material. One fragment is separated from the body of the female frog, and is called the *egg-cell.* The frog's egg-cell is a sphere about one-sixteenth of an inch across. It contains two sorts of living fabric: there is a *nucleus,* a small, globular core, and there is the *cytoplasm,* a mass of semi-liquid stuff around the nucleus. The cytoplasm contains a good many droplets of yolk, which is the food for the growing egg. The whole egg-cell is enclosed by two thin skins, and outside these by a material which swells up into the familiar jelly around the frog's egg. This frog's egg-cell is not quite comparable to a hen's egg on the breakfast table. The yolky part of the hen's egg (provided you are not eating an egg that is developing) is just an egg-cell which contains an exceptionally large amount of yolk. The jelly around the frog's egg-cell corresponds to the white of a hen's

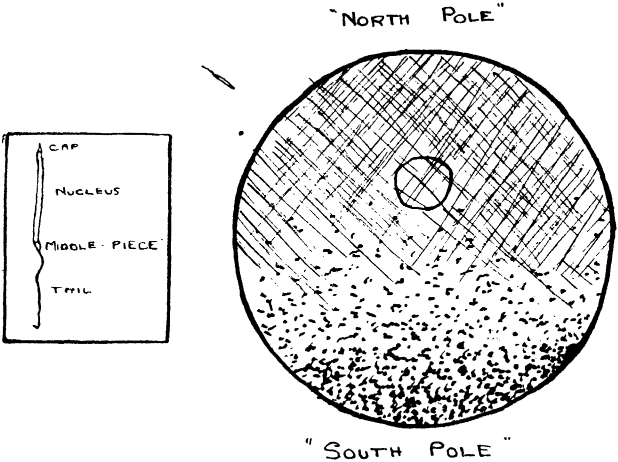

FIGURE 1. Diagram of the egg-cell and male-cell of the frog. The nucleus and cytoplasm of the egg-cell are seen. The pigment of the egg-cell is indicated by the cross-hatching, the yolk droplets by the black dots. A male-cell, drawn to the same scale as the egg-cell, is seen approaching the "north-west" quarter of the egg. A frog's male-cell is $\frac{1}{100}$ inch long, while a frog's egg-cell is $\frac{1}{10}$ inch across. Inset: A male-cell still further enlarged to show details.

egg but there is no shell to envelop it. Having less yolk than a hen's egg-cell, the frog's is much smaller in size.

The fragment coming from the male frog, the *male-cell*, is far smaller than the egg-cell. It consists of little more than a bare nucleus, like that of the egg-cell, equipped with a tail behind, which can drive it through liquid.

Neither the male, nor the female, fragment of living material develops on its own into a new frog. Development begins after the male-cell has been engulfed by the egg-cell, and a single lump of living material has been formed. This is brought about by the sexual intercourse of the male and female frogs, who carry inside themselves the cells which will go to begin the next generation. During sexual congress, numbers of eggs are shed by the female frog into the pond where copulation occurs and, at the same time, the " seed," or *semen*, of the male is poured over them. The seed contains a huge number of male-cells, at least one of which penetrates each egg-cell. The nucleus of the male-cell, now inside the egg, joins with that of the egg-cell to form a single nucleus. This union of the male and female fragments of living material is known as fertilisation, and its product is the fertilised egg-cell, or fertilised egg.

The process of reproduction in human beings differs principally from that of the frog in that the egg-cell is not shed to the outside, but is fertilised inside the body of the woman. The fertilised human egg settles in the womb, where, fed from its mother's blood, it develops for nine months before it is born.

The fertilised egg consists of a single nucleus embedded in a mass of cytoplasm. It is the property of this single fragment of double origin, left on its own in the pond, to grow and change in such a way that it becomes a frog. What is the nature of this remarkable development? Can one see in miniature inside this single fertile cell each of the parts of the body of a full-grown frog? If so, do these simply unfold in a regular way, like a paper decoration can be unfolded, or like a toy Japanese flower spreads out in water? The development is not so simple. The largest magnification of the fertilised egg by the microscope fails to reveal to the eye the folded-up parts of the future frog. Experiments prove the point: if you cut any piece off a folded paper decoration there is a gap somewhere when it is spread out; if you chop a small piece from most parts of the cytoplasm of the fertilised frog's egg, the remainder can still grow into a whole frog. But perhaps it is the nucleus of the egg which contains the folded-up adult? This idea is nearer the truth, but it is by no means true. The nucleus of the fertilised egg does in fact contain a set of specially important minute particles. These particles, which are called *genes*, will imprint upon the developing frog the characteristics of its parents. The genes are the carriers of hereditary features. That means that if you could cut a chunk off the nucleus of the fertilised egg, the frog which finally took shape would be deficient or abnormal in some way; but it does not mean that the nucleus unfolds mechanically like a paper decoration. For the first move in development is made by the nucleus, which divides into two *daughter-nuclei*. Experiment shows that either of these two daughter-nuclei, separated from the other and given a suitable piece of cytoplasm to lodge in, can develop into a whole young frog. This is because, when the nucleus divides, it provides each daughter with a complete set of its own genes.

While the nucleus is dividing, the rest of the egg is also cleft into two, making the whole into two compartments, each containing one nucleus, and a mass of cytoplasm, enclosed by a thin skin. Further divisions like this separate the living material into more and more compartments. Each of these is technically known as a *cell* (the egg-cells and the male-cells are compartments of living material separated off from the other cells of parent frogs). The adult frog ends up with a body composed of a great number of cells. The nucleus of each of these is similar to the nucleus of the original cell. The nucleus, in fact, does not unfold, but it influences the living material in which it is situated, while the frog is developing, so as to mould the final shape of the frog. But this is not the whole story: the interactions are more subtle. For certain regions of the developing egg, or *embryo* as it is best called, grow different from other regions, and the different parts influence each other.

This story may seem involved, but it is the simplest clear picture of what makes an animal take shape. In this and the next chapter we shall be in the thick of going into the two aspects of the relationship. In the rest of this chapter we shall discuss how parts of the embryo become the head, stomach, backbone, and other organs of the frog. In the next we shall discuss how the

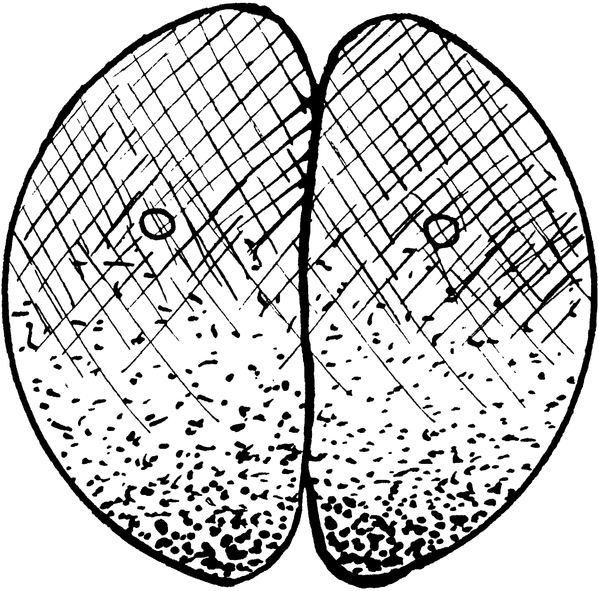

FIGURE 2. The fertilised egg after its first division. The same conventions are used as in Figure 1.

set of genes in the nucleus convey the shapes, colours, and the multitude of features, which make the individuality of an animal, from one generation to the next.

It has been seen that the fertilised egg-cell is a piece of living matter with a single nucleus, and the grown frog has many organs, each composed of many cells, all working together. Our problem is how the simple egg becomes the complicated adult. The ground can be cleared first by noticing that this development happens in three ways. To begin with there is obviously a growth in size, an increase in the amount of living material. Living matter, though it does not any longer come into being on its own, can very easily increase its bulk by turning the chemicals that come its way into its own fabric. These chemicals, that are the raw material for growth, are obtained first from the yolk, and in later stages from the food eaten.

The second thing happening as a frog develops is the cleaving of the egg into more and more cells. Third, and most important, masses of cells in one region become different from those in other regions, and thus the growing egg becomes separated into parts or organs. Of these three types of event it is on the last that we shall concentrate.

Development begins as follows: a fertilised egg divides first into two, then again into more and more cells. Divisions like these produce a bunch of cells which are unequal in size. As the process of cleaving goes on, the bunch becomes a hollow ball, because the cells move outwards away from each other. In the hollow ball some differences between the cells are already evident. Those on the top of the sphere have divided more often than those at the bottom; they have thus become smaller, because at this stage the living material is not increasing in volume. At a stage when it contains more than a thousand cells the ball begins to behave in a new way. A dimple appears on the surface. Cells in the area around the dimple begin to spread sideways and to elbow each other and crowd towards the inpushing. With these movements, the dimple becomes deeper, and the cells in and around it plunge into the middle of the ball. Some of the surface cells are now inside the ball, or on the edge of the hole, which remains to mark the point where the others plunged in. After a time the cells inside the ball arrange themselves in two layers, one encircling the other. This makes the embryo into a sphere of three layers—outer, middle, and inner. Each of these three layers has its own fate. The outer layer will develop into

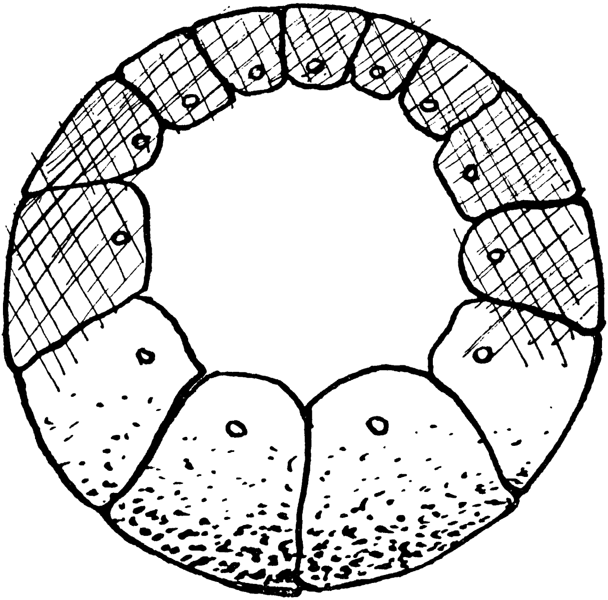

FIGURE 3. The hollow ball of cells—a section simplified. The same conventions are used as in Figure 1.

nerves and skin; the middle will become blood, bones, muscles, and the fabric of many other organs; the inner gives rise to the lining of the lungs, of the stomach, and of the other organs of digestion. Differences in position and in quality between the cells have arisen, and you have the beginning of the organisation of the frog into working parts.

How do parts of the developing frog's egg become in this way different from one another? What are the

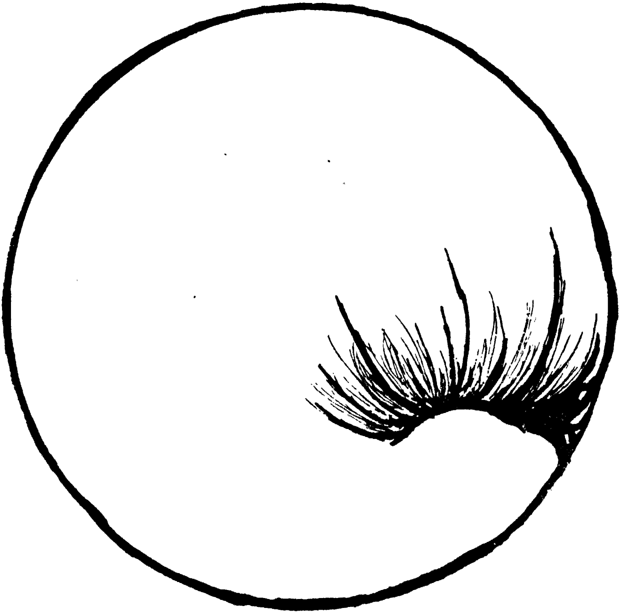

FIGURE 4. The inpushing of the dimple, an imaginary view from outside the hollow ball.

causes which make them grow in a concerted and ordered way? To deal with this problem we must go back to the unfertilised egg-cell. The frog's egg-cell when laid, already has, as it were, a " north " and a " south " pole. One pole is black in colour, the other is uncoloured and full of droplets of yolk. Observation shows that the darkly coloured pole, which is here called

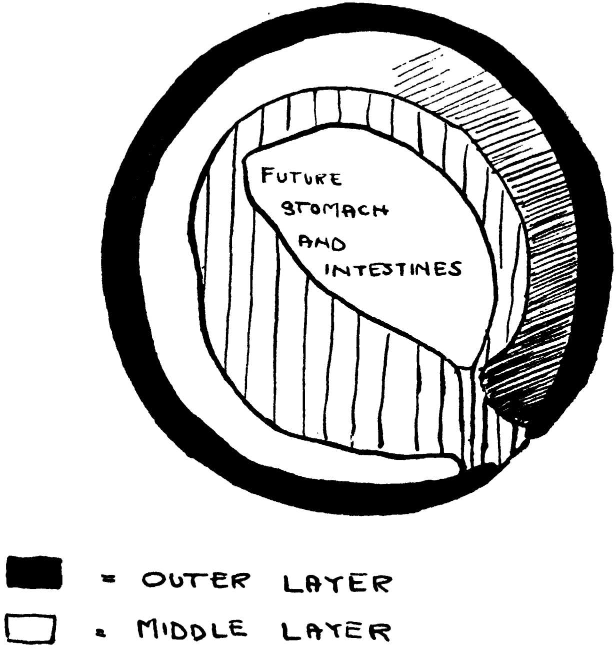

FIGURE 5. Diagram of a section of the embryo in a three-layered stage, showing the location of the organisation centre.

north (as it lies uppermost), will become the head-end of the frog, while the yolky south pole will be the hind-end. For reasons not exactly known, there is therefore already, before the male-cell enters it, a difference between one end of the egg-cell and the other. This is a difference in degree rather than a difference in kind. There is a

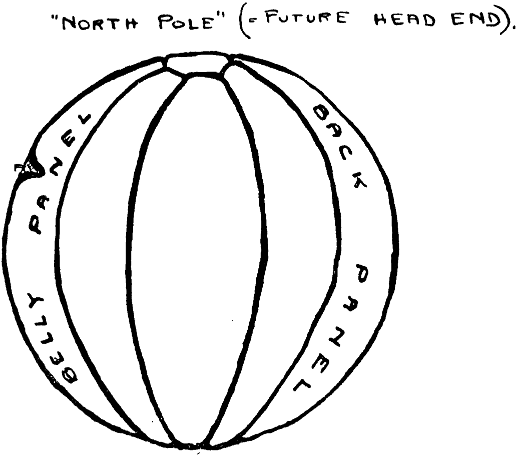

FIGURE 6. The fertilised egg-cell divided into imaginary panels like a football.

gradual lessening in the quantity of colour and an increase in the amount of yolk as we leave the north pole and pass through the egg to the south pole. This is thought to go with a corresponding lessening in the activity of the cytoplasm. Thus you have in the unfertilised egg-cell a gradient of quantity from one pole to the other, as you would have a gradient in hotness from the hot end of a red-hot poker to the cool end. These differences in degree forerun the future difference in quality between a frog's head and a frog's hind-end.

The next event which affects the pattern of development is the entry of the male-cell into the egg-cell. Imagine the surface of the egg-cell to be divided up, like a certain type of football, into panels which spread from pole to pole. The panel in which the male-cell chances to penetrate the egg-cell will become the belly of the frog. The panel diametrically opposite this will become the back of the frog. In this back panel also, near the south or hind-end, the dimple already described will appear. The first decisions of the form of the future frog are taken, therefore, before the fertilised egg divides into cells. Its subsequent division into compartments does not alter the arrangement of the whole.

The panel which is to become the back has yet another important property: the egg cannot develop without it. If this region is separated from the rest by a hair tied round it, then the rest will not develop. (This experiment was done on the egg of a newt, a relative of the frog.) It is not known what makes the bunch of cells, first produced by division, form a hollow ball; nor is it known exactly what causes the dimple in the surface of the ball. But after this inpushing has occurred, certain cells that direct and control further development can be distinguished from the rest. These cells run northwards, in the middle layer, from the northern lip of the hole. They are known as the *organisation centre*. They come from that important panel of the fertilised egg opposite the point where the male-cell entered. The organisation centre causes the cells of the adjoining outer layer to grow and move in such a way that they throw up two folds running along the back of the embryo. These folds grow together and form a tube: it is the beginning of the nervous system of the future frog.

If the organisation centre is cut out, and grafted into another egg at the same stage of development (this is how its properties were investigated) it will make a pair of nerve-folds appear in its host embryo. Thus the host will come to possess two pairs of folds. Deprived of its organisation centre, the first egg does not continue to develop. The action of the centre can be imitated in part by certain chemicals. If these are applied to an embryo at the right stage, they cause it to throw up two nerve-folds. The action of the centre is only by consent, so to speak, of the parts it organises. For only at a certain period in the growth of the embryo are the cells susceptible to the action of the centre: earlier or later than this susceptible period it has no power over them. The centre, in fact, does not initiate the development of the egg; it brings about changes in other parts, which are themselves already developing. Further, at the stage when it becomes active, the centre is itself under other influences, like those that make the head-end different from the hind-end of the animal.

After the organisation centre has acted, the fates of each main part of the embryo are settled. Each main region is then irrevocably determined to become its appropriate part of the adult, and the whole embryo is a collection of parts, harmoniously growing on their own and not much affected by each other. Within these autonomous regions, secondary organisation centres arise and arrange further details. At the stage at which the main fates are settled, the backbone is roughly modelled as a single rod. This rod is later reorganised in detail into a chain of interlocking bones.

The egg develops thus until it has a fish-like form, and leaves its jelly coat. It is now a tadpole without legs; it feeds, and grows its legs, in the pond where it hatches. When all four legs are well grown, there comes a crisis in its development, and, by a rapid loss of its tail and by other violent changes, the tadpole is converted into a frog.

The story of the organisation centre, which has been narrated in the frog, has been found to have parallels in other animals, like a grasshopper, a newt, and a chicken. But it has not yet been possible to look so closely at how the majority of animals or at how plants develop.

We have seen that an egg does not simply unfold into an adult: it develops from being simple to being complex. Two words—separation and interaction—best express the ways this change happens. On the principle of " to those that have shall be given," small differences between one part of the egg and another become magnified during growth. Then one of these separate parts organises others, which are responsive to its influence. Biologists are as yet uncertain as to how the egg gets divided into different regions. Living material exists in a subtle state of balance. The balance is between a number of forces which act in roughly opposite directions. Some forces make towards the construction of substances inside the cell; others towards the breaking down of these substances. With the existence of this inner opposition it is not difficult to imagine that a slight difference in conditions may produce definite differences of a chemical nature between one part and another. " Without contraries," wrote Blake, " is no progression." It is in the fundamental contraries which oppose each other in the living egg-cell that we may find the driving forces that divide the egg into parts.

The above facts result from researches carried out in England and Germany during the present century. These researches were made possible by the improvements in surgery in the latter part of the last century. They have not yet yielded any invention of practical value; but they have helped to elucidate something of the logic of development.

CHAPTER VII

LIKE BEGETS LIKE

THIS IS ONE of the most striking paradoxes that the living world presents: like begets like from one generation to another, yet modern species have evolved from ancient ancestors which they do not in the least resemble. Tracing backwards, to-day's mammals are descended from reptile-like, then fish-like, then bone-less creatures. A solution of this paradox must be found in the machinery of inheritance.

A man may inherit his father's house or he may inherit his father's eyebrows. In one case he is receiving goods, in the other he has received a piece of living material. He received this living material from the male-cell of his father which fertilised the maternal egg-cell. Like begets like because material is passed on from parents to offspring; the ingredients of a fertilised egg are the combination of ingredients from each parent. The combination in one egg is different from that in another egg. The stuff of a frog's egg, for instance, is only minutely dissimilar from that of the egg of another frog of the same species, definitely distinct from that of a newt's egg, and in many more ways unlike that of a grasshopper's egg.

Many experiments show that a piece of living material has its own individuality. This has been proved by inserting cells from a developing frog's egg—or embryo—into the embryo of its relative, a newt. Cells of a frog's embryo in an early stage can be cut out before their fate in the future frog is irrevocably determined. If these undecided cells are then grafted into a newt's embryo in the same stage they will take part in the development of the newt. They are moulded by the newt's organisation centre into the part of the newt appropriate to their position in its embryo. Thus, if they are replacing the cells that were to become the mouth, they instead will become the mouth of the newt. But the cells will have the colour, size, and arrangement that they would have had in a frog's, and not in a newt's, mouth. The frog's cells have a " froggishness " of their own.

It will be remembered that, on fertilisation, the nucleus of the male-cell fuses with the nucleus of the egg-cell making the single nucleus of the fertilised egg. A father's share in the individuality of his offspring must be conveyed into the egg by the nucleus of his male-cell. Since it is found that, on the average, father and mother contribute equally to the features of a child, it is concluded that the nuclei of male-cell and egg-cell (rather than the cytoplasm of the egg) bear the individuality from one generation to the next. There is to-day ample evidence to show that a set of definite bodies within the nucleus of the fertilised egg determine the features of the adult.

As it will be remembered, these bodies are called genes. Male and egg nuclei each contain a half set of genes. When the two meet, the egg has a whole set. If, then, we want to study how the features of an animal or a plant are inherited, we must trace the passing on and the manifestation of genes.

Though much is known about genes, they are too small to be visible even when the microscope is used at its strongest. Our knowledge of them is derived from a study of their effects—from the way they influence the features of the whole living being in which they reign. Each gene acts as a definite unit of inheritance and presides, usually in a pair with one other, over the formation of a certain feature or features of the adult. Consequently, though it is invisible, a gene is concluded to be a distinct body and it is even possible to guess at its size.[1] The width of these invisible particles has been variously estimated at between one-millionth and four-millionths of an inch. A set of genes consists of a number of different pairs, each pair being concerned with one or more features. In a half-set of genes (such as exists in the male or egg nucleus before fertilisation) only one member of each pair is present.

It was seen how a fertilised egg divides into more and more cells. In this process, whenever a nucleus divides, each gene in it makes a copy of itself. Consequently each of the two daughter-nuclei is equipped with exactly the same set as the undivided nucleus. Any of the first thirty-two nuclei resulting from the division of the fertilised egg of a newt is capable of becoming, when lodged in a suitable piece of cytoplasm, a whole new newt. But there is one case when the genes do not multiply during the division of a nucleus; instead, the gene-pairs split apart. This occurs when the reproductive cells are being formed. One alone from each pair of genes goes into the nucleus of each reproductive cell. On fertilisation, when the male and female nuclei fuse, the solitary genes form pairs again. But each of the new gene-pairs has one gene in it derived from each parent. A new combination has resulted and new properties may ensue.

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[1] The genes are known to lie on definite bodies in the nucleus called *chromosomes*, which become visible during the division.

The influence of a pair of genes of one type on the colour of a bird can be seen in the breeding of the Andalusian fowl. Take a black Andalusian cock and a white Andalusian hen. The blackness of the cock is due to the action of one pair of genes, which we shall call the " black genes." The whiteness of the hen is due to a pair of " white genes." Both black and white are genes of one type, which affect one feature—the colour of the bird. A black and a white gene, being of the same type, can form a pair together. In the making of the reproductive cells of cock and hen the pairs of genes are split. In the cock, one black gene goes into each male-cell; likewise, in the hen, one white gene goes into each egg-cell. When the birds are crossed the reproductive cells unite, and the nucleus of the fertilised egg will then contain a mixed pair of colour-genes—one black, one white. The mixed gene-pair, taking effect in the cells that form the feathers of the growing chick, dyes the feathers the slaty hue of the blue Andalusian fowl. Exactly the same result is obtained if a white cock is crossed with a black hen.

This is a simple case, because each gene in the pair has some effect on the colour of the bird. Sometimes, in a mixed pair, one gene dominates the other, and this dominant gene alone affects the individual. When this happens the feature of only one parent is seen in the first generation of offspring. If a tall pea-plant is crossed with a dwarf pea-plant, all the offspring are tall. They all contain one gene for tallness and one for dwarfness in each nucleus; but the tall gene dominates. The different possible ways genes in a pair may behave towards one another is reminiscent of the behaviours of various married couples. A gene that manifests itself when in a mixed pair is known as a *dominant*, the gene that is dominated is known as a *recessive*.

To return to the blue Andalusians. What will happen if the birds of the blue generation, containing a mixed pair of genes for colour, are crossed together ? When the birds' reproductive cells are formed the gene-pairs will be split. Half the egg- and male-cells will get only a white gene; the other half will get only a black gene. On crossing, the black and the white reproductive cells can combine in several ways. A black may meet another black, or it may meet a white; a white may meet another white, or it may meet a black. Out of every four fertilised eggs, on an average, one will contain two blacks, one will contain two whites, and two will contain mixed black and white genes. Crossing the blue Andalusians, therefore, would be expected to, and does, produce three types of fowls in the proportion of one black and one white to two blue.

The result of crossing the offspring of the tall and dwarf pea-plant, in which the tall gene dominates the recessive dwarf, would naturally be different. The gene pairs will divide and recombine in the same ways as in the fowl, but all the plants with a tall gene in them will be tall, while only plants with two dwarf genes in a pair will be dwarf.

How are these genetical principles made use of in practice ? When a tall and a dwarf pea are crossed, the dwarf character skips a generation and reappears in a quarter of their " grandchildren." Suppose the original dwarf and tall plants differ also in the colour of their flowers, the dwarf's being white and the tall's coloured. If these pea-plants are crossed, it is found that the colour of the flower is inherited independently of the height of the plant. As the white gene is recessive to the coloured, all the children of the cross are tall with coloured flowers. But among the grandchildren all the possible combinations crop up, including a minority of dwarf and white-flowered plants. The principles of " dominance " and of the " independent assortment of genes " were both discovered by the Abbé Mendel. Though neither is always true, they both apply in many cases and can be of great assistance to breeders. A case where the principles of

Mendel have been used in practice is excellently described by Wells, Huxley, and Wells:

> "This method has been applied with great practical success to wheat by Sir Rowland Biffen. The National Association of British and Irish Millers, dissatisfied with the wheats at their disposal, requested Biffen to try to improve them. They demanded a beardless wheat, immune to the fungus disease known as rust, with a high yield per acre, and with 'hard' grain, rich in gluten, and so of good milling and bread-making quality. No known variety combined all these characters, so Biffen set himself to make one. He crossed a rust-resistant grain of low yield and poor grain-quality with a wheat of good quality but great susceptibility to disease. All the first generation were susceptible to rust. This was no discouragement to a Mendelian, so Biffen obtained a large second generation by self-fertilisation, and his expectations were justified by finding, among the large number of recombinations which appeared, some plants which combined rust-resistance with the desirable qualities of the susceptible stock. The two main strains which he manufactured by Mendelian principles, 'Little Joss' and 'Yeoman,' though only put on the market in 1912 and 1917 respectively, by 1927 occupied about a third of the wheat-growing area of the world."[1]

Bearing in mind the basic principle, that parts of nature and of living beings interact one on another, we should expect the influence of genes to depend on the conditions they are in. There are three main conditions that may modify their action in the body:

(1) A single sort of gene, present in the nucleus of each cell of the body, may have different effects in different portions of the creature. This is the case with a certain gene in the fruit-fly. In the cells of the eye, this gene makes the colour white instead of the normal red; the same gene, in the cells of the male-gland, causes a change in colour of its coat. During development, the

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[1] *The Science of Life*, H. G. Wells, Julian Huxley, G. P. Wells. Cassell.

genes interact with the various organisation centres of the embryo.

(2) The influence of a gene may depend on the climatic and such-like conditions in which a creature is reared. There is an uncommon gene in the fruit-fly which distorts the shape of the abdomen during its growth. When this gene is present in an egg, it only takes effect when the young are reared in moist conditions, but not if they are reared in dry.

(3) The action of one gene-pair is affected by other pairs in the nucleus. The colour of a mouse may depend on the combined action of genes of two or three different pairs. The interaction of genes is so various that biologists have realised (though only lately) that the nucleus must be looked upon, not as a collection of independent gene-pairs, but as a whole—a *gene-complex* as it is now called. Twentieth-century biologists made at first the same kind of mistake as Linnæus had made in the eighteenth century: they tended to look upon genes as separate particles which did not affect each other; while he believed in the fixity of the races of living beings.

Like begets like because genes are copied when each nucleus divides, and genes (being passed from an animal or plant into its reproductive cells) are handed down from generation to generation. How does like come to beget unlike? But first, *how* unlike are the living beings of the world? Though a plant and an animal have very different features and, therefore, gene-complexes, they possess the same complicated mechanisms of inheritance and of cell-division. There is unity behind the diversity of living forms: the question to be answered is how genes and gene-complexes come to alter.

Genes in a living body are relatively hard to alter. The activities of an animal during its life do not, as far as is certainly known, change the genes it passes on to its children. Though the feet of Chinese girls have been bound up, and various other distortions of the body practised traditionally by sections of the human species, for a hundred or more generations, there is no sign of these practices having changed the features of a new-born baby. The genes travel on from generation to generation without being modified by what happens to the vehicle they travel in. A railway train provides some comparison. The passengers in it (corresponding to the genes) do not have their constitutions altered by the meadows, hills, woods, or tunnels through which the train passes. But if there is a war on, and the train is subject to an aerial machine-gun attack, the constitutions of some of the passengers may well be changed. Likewise, if a living being is bombarded with rays, especially if they are X-rays, some of its genes may be altered in constitution. Occasionally genes change on their own: the alteration of the gene is known as a *gene-mutation.*

In stocks, like those of the fruit-fly, which have been kept for many years and millions of individuals of which have been bred, it is possible to calculate very roughly how often some genes do change. The commonest gene to change in a way that is detectable is one affecting the colour of the eyes. This is found to mutate in one out of about every 300,000 individuals. In man, some genes seem to alter slightly more often than this, to judge by the cropping up of certain hereditary defects, like *hæmophilia.* The blood of individuals suffering from this defect clots very slowly, and they may bleed to death from a cut. A normal gene mutates into a hæmophilic gene once in about every 150,000 individuals.

A stock may change, too, if the mechanism of nuclear division goes wrong. Imperfect division may rearrange the chromosomes that bear the genes, or may multiply their number. New types of individuals may come from reproductive cells whose nuclei are altered thus. People are just learning that wounding a tissue or subjecting it to extremes of temperature may induce changes of this nature. Again, fresh creatures may be made by combining two different gene-complexes. This can be done by the difficult business of crossing two species: when two particular species of fish are hybridised, a gene which causes one species to be black in colour produces black warts in the offspring.[1] Many fresh strains and several new species have been created in this way. Dutch and Indian scientists have made new sugar-canes by hybridising wild and cultivated species; Harland has produced new cotton-plants in Trinidad by like methods; the Canadians have crossed two species of wheat to create a strain, appropriately named Hope, which reaches a new high level in its powers of resisting disease; the Russians have created a " perennial wheat " by hybridising couch-grass and wheat. Like its wild parent, the new plant springs up every year from the same root; like its crop parent, it bears grain.[2]

CHAPTER VIII

VARIETY

FOR THE BIOLOGIST there are three worlds of size—the visible, the microscopic, and the sub-microscopic. A spectator, moving down the scale of size from the largest living beings (like 300-foot Sequoia trees or 90-foot whales), will pass elephants, mice, and fleas before his unaided eyes fail him. Taking up instruments to help his sight, he will find a world of microscopic living forms; and, crossing the lowest limit of microscopic vision, at about a hundred-thousandth part of an inch, he will discover by devious tests an invisible world of sub-microscopic beings. Continuing his survey, he must descend below specks of less than a three-millionth part of an inch before he reaches a plane of size where no bodies have the unique properties of life. Foot-and-mouth disease is due to invisible parasites in cattle, estimated to be particles about a two-and-a-half-millionth of an inch across, yet having the vital property of being able to build themselves up out of materials unlike themselves.

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[1] *The Causes of Evolution*, J. B. S. Haldane. Longmans, Green.

[2] For a full review of the possibilities of gene-science to-day see " Genetics in its Application to Plant Breeding," by P. S. Hudson, in *Biological Reviews*, Volume XII, page 285.

The most advanced animals, whose bodies have attained the maximum of convenience and suitability, have their frame pivoted on a skeleton with backbone, jaw-bones, and legs, and they maintain their body at an even, warm temperature by means of hair (or clothes), sweating, feathers, and other devices. These advanced types include the mammals (to which man and other hairy animals belong) and the birds. Reptiles (including lizards, etc.) and *Amphibia* (frogs, newts, and their allies) differ from birds and mammals in their inability to maintain their bodies at an even temperature. Amphibia, too, must (as we saw) spend part of their lives in water. Fish also have backbone and jaws, while a few simpler fish-like forms, the lampreys, possess no jaws. Among the animals without backbones are groups typified by insects and crabs, starfish, snails, worms, and anemones. The skeleton of insects and crabs lies outside their body, and, around each of their numerous limbs, it takes the shape of a brittle, jointed tube. The body of a starfish is enclosed by skeletal plates of a different material from the coat of crabs; but worms, snails, and anemones are soft and limbless, and, if they have hard parts, these are, with few exceptions, no more than an inanimate shell. The most advanced plants and trees bear flowers; while the various simpler flowerless groups include ferns, mosses, seaweeds, and lichens on the rocks.

It is in their structural arrangement that the visible and the microscopic worlds differ most obviously. The cell is the unit of construction of bodies in both worlds, but, whereas the plants and animals listed above are composed of many cells, most microscopic forms carry out all the operations of their lives within a single cell. The larger microscopic bodies, ranging downwards from about a tenth of an inch in length, have their cell divided into nucleus and cytoplasm. They live in the soil, in the sea or fresh-water, or in the blood or other fluids of larger creatures. Some of them move about and eat solid food. *Amœba*, the darling of the textbooks, is a common genus of beings of this type. Some Amœbæ live in fresh-water, some in sea-water, while a parasitic relative of theirs, *Entamœba histolytica*, lives in men and causes a form of dysentery. Others of these nucleated, one-celled beings, such as those that form the green scum on ponds, are green and stationary, and get their living in the same way as plants do (see Chapter IX). Some types, intermediate between plant-like and animal-like forms, are both green and moving. Other beings, like the yeasts, with nucleated cells, are stationary and colourless, and live on the sugar made by plants.

The microbes, whose cell is not divided into nucleus and cytoplasm, make up the smaller half of the microscopic world. A large microbe reaches the length of about a three-thousandth part of an inch, while the smallest microbes pass just below the limit of microscopic vision: 1,600 of these in a row would fit into the breadth of a fine line drawn by a mapping pen. Many microbes live in the soil or in water, and there play an important part in the chemical cycles of nature; others (as the reader is aware) are the agents of certain diseases like consumption, anthrax, and typhoid. Usually one kind of microbe is responsible for a particular disease. Having entered their host with water drunk, with air inhaled, or with dirt in a wound, the disease-causing microbes multiply by repeatedly dividing into two. The excretions of their living bodies and the chemicals in their corpses mainly cause the illness. The animal they enter is normally able to develop powers of resisting the microbes, and it may succeed in destroying them, and in surviving their poisons.

At the bottom of the scale of organisation are the bodies known as *viruses* and *bacteriophages*. These are smaller than anything that can be seen with the microscope, and our knowledge of them is derived from their indirect effects. Fluids taken from animals or plants with certain illnesses, like foot-and-mouth disease, rabies, or the mosaic-disease of tobacco plants, can be strained with a fine filter of all particles large enough to be visible under the microscope. Yet these fluids can still spread infection to another host: they contain sub-microscopic specks—the viruses—which can grow and multiply in the bodies of larger creatures, though they cannot increase without a living host to dwell in. Our knowledge of viruses is at present fragmentary, but a start has been made in Cambridge at analysing their structure by the use of X-rays, which can elucidate far smaller objects than can a microscope. The viruses that attack cucumber and tobacco plants appear to consist of numbers of very minute particles, a good deal longer than they are broad. In certain conditions these particles stack themselves in regular bundles.

A survey of the various forms of life reveals something of the course of their slow historical development. As living material has advanced into more and more elaborate plants and animals, at each stage species have been left behind. Some early types are still alive to-day: the limpet of the sea-shore is now much the same kind of animal as it was about 400 million years ago. Yet at that time, flowers, birds, and mammals had not come into existence. Just as savage tribes, cut off from the rest of humanity and from raw materials, and settled in a convenient niche, give us an idea of the past of modern industrial societies, so the diversity of living forms, studied in conjunction with the remains or imprints of ancient creatures in the rocks, gives us a panorama of evolution.

In all its development of bodily complexity, living material maintains an unbroken stream from generation to generation. In the simplest cellular forms, like the microbes, the stream is kept flowing by the division of the cell, from time to time, into two. Each cell is a generation. In a highly developed species, like a frog or a daisy, the stream is less simple. Only a few of the adult's cells —the reproductive cells—form the next generation; and each fertilised egg is derived from two parents, so that the stream of life is interlacing. Yet, still, each individual is the elaborated product of a single cell—the fertilised egg-cell. Looked at in a simplified way, the evolution of more complex forms is the evolution of egg-cells with a higher and higher potential for growth and development.

Nerves have been left out of this bare outline of evolution because they do not exist in the vegetable kingdom but especially belong to animals. Even the tallest tree co-ordinates its life without the aid of a nervous system. The evolution of nervous systems, from a scanty network of nerve-cells in a creature like the sea-anemone to the intricate brain and nerve-cord of the highest animals, goes hand-in-hand with the development of more precise movement, for getting food, for defence, and for escape. A brief account of this evolution is given in Chapter X. Everything in nature is linked together, but description isolates events and forces things which happen abreast to be set down in single file. Unless the reader is prepared to do his own synchronising and continuity work, by turning backwards and forwards in the book, he will find an account of biology about as enjoyable as sitting through a talkie where the pictures and sound are separated and shown one after the other.

CHAPTER IX

THE INTERLACING OF LIVES

MAN'S RELATIONSHIP to the species which directly affect him may be one either of exploitation or of defence. Different yeasts and moulds stand in both these relations to man: they can spoil stores and damage crops, and they can carry out valuable chemical processes. A yeast consists of a number of single cells or of a chain of similar cells. Varieties of domestic yeasts live on sugar, which, in the process of carrying on their own lives, they convert into other chemicals. The moulds live in the same kind of way as yeasts, though they may feed on more diverse objects, like bread, boots, wood, or living plants or animals. As chemists, yeasts and moulds are employed in the conversion of sugar and starch into alcohol, glycerine, citric acid, and other products. In baking, yeast makes the bread rise by liberating gases into it, and, in brewing, it produces the alcohols. Between 1914 and 1935 there were patented over eighteen hundred ways of using moulds and yeasts in chemical industries. They promise to be especially useful in carrying out delicate chemical operations on a small scale. Three foodstuffs of great importance to health, but only required in minute quantities, are Vitamin D, Vitamin B1, and Vitamin B2 (see Chapter XI). Experiments show that Vitamins B1 and B2 can be obtained from yeast, and that a mould can be used to manufacture Vitamin D. This vitamin is a crystalline solid, made by the action of ultra-violet light on the chemical, *ergosterol*, which is produced by the mould.

Though their origins have been mostly lost sight of, man's crops are derived from wild species. In searching for useful varieties of crop-plants, which had been forgotten by modern farmers, but which are still grown in regions of primitive agriculture, Vavilov unearthed some of their origins. He was able to make out many of the areas where wild plants had been first turned into farm crops. The main fruits, like apples, pears, cherries, peaches, apricots, and grapes, were domesticated in the valleys of Persia; figs and olives were brought into cultivation in the Mediterranean Basin; Abyssinia is probably the home of some wheat and of barley. In general, new species of plants originated in tropical and sub-tropical mountain regions. Pursuing its studies further, the school of Vavilov was able to explain along the following lines the beginning of the cultivation of rye. In southern regions, winter rye occurs mixed in crops of winter wheat, where it is of little use as a crop and can really be considered a weed. Because its seed is difficult to separate from the wheat seed, some rye was included with the wheat, when the seeds of winter wheat were transported northwards. But the weed rye, in cold climates, withstands the rigours better than the wheat, and hence it thrives and produces more grain than the crop itself. In this way, rye, unwittingly transported northwards as a weed of wheat, is taken over as a crop-plant in colder climates.

The other side of human contact with the rest of living beings is one of defence. Man is attacked by a large number of different parasites—viruses, microbes, single-celled forms with nuclei, and many-celled animals. His crops and herds, too, are frequently decimated by them. Man is a particularly vulnerable target for parasites, because he lives close to his fellows in large populations. By this proximity of man to man, the passage of the parasites to new hosts is made easier.

Parasites which cause the most serious ill-health to man live inside his body. Among the most important of these is the blood-fluke, *Schistosoma*. It was estimated in 1924 that 70 to 80 per cent of the total population of Egypt were infected with blood-flukes. This is said to account, in part, for the backward condition of the Egyptian peasantry, but the prevalence of *Schistosoma* is itself a product of the backward economic and hygienic condition of the country. In Egypt, or in other countries where blood-flukes abound, anyone washing in, or drinking, dirty water is liable to be infected with the parasites. The young flukes in the water bore their way into the human body. Once inside the body, they grow up. The adult flukes, which are many-celled, small, soft, flattish, worm-like animals, live in couples in human veins. They lay their eggs next to the wall of the bladder or of the *rectum*, which is the passage between the intestines and the exterior. The eggs make their way into the bladder or the rectum, and are emptied from the body. If they reach water, the eggs hatch into young, which enter one of the many water-snails present in uncared-for ponds and rivers. After living inside the snail, young flukes emerge from it in a new form. At this stage, the new generation is again able to bore its way into the bodies of any who wash in or drink the water.

The flukes first cause the general debility of their hosts; later they make passing water extremely painful. They can be got rid of by the use of *tartar emetic*, but the most effective defence against them is to prevent them ever reaching the human body. This is best done by rooting out the water-snails in which the fluke passes part of its life. Treatment of the water-supply of a village with traces of the chemical, *copper sulphate*, will kill the water-snails and, accompanied by treatment of the inhabitants, will free the place of blood-flukes.

Other diseases of great importance, such as malaria, yellow-fever, and sleeping-sickness, are due to parasites conveyed by flying insects which bite man. Malaria ravages the tropical regions of the world and marshy districts in temperate climates. In 1936 malaria killed 1,680,000 Indians, while there was available less than one-sixth of the quinine needed to combat it. Malaria and yellow-fever are carried by mosquitoes, while sleeping-sickness, due to one-celled organisms belonging to a group known as *Trypanosomes*, is carried by the tsetse fly. Combinations of these three diseases make it impossible to live in large tracts of potentially valuable tropical land. Yet the diseases can be completely eliminated from a region, as they have been from the Panama Canal Zone. The best method of conquering them, as with the blood-flukes, is to exterminate those species of animal which convey them.

The living beings which directly affect man are only a fraction of the total number of species. All affect him indirectly, for all plants, animals, and other creatures are connected together in a relationship which extends over the globe, and there is no species whose life is not linked with the lives of other species. The total number of living things involved in this global relationship is astonishingly great. It has been calculated that there are 4,000 odd living bodies, omitting microbes, in every cubic foot of sea-water. There are about 8,000 earth-worms in the upper nine inches of soil in every acre. And there are 4½ million insects on and in the upper four inches in the same area of soil.

Numerous as are adult creatures, eggs laid or seeds set by them are far more numerous. A tape-worm, for example, is said to be able to discharge 800,000 eggs per day. If these ever reached maturity, we should all be infected with tape-worms many times over. Agricultural experts have made a careful analysis of what happens to the young of certain pests. As an example, we can take their studies of the corn-borer, a moth whose young burrow into the stems of corn, badly damaging the crop. During a survey of the life of the corn-borer in France, some average figures were calculated. It was estimated that, out of every 200 eggs produced by this moth, an average of 10 are sterile and do not develop. Another 19 are killed by parasites. After the remaining eggs hatch into the young, 137 out of the original 200 die owing to their intrinsic inability to obtain food, to withstand the weather, etc. Another 20 of the 200 are killed by parasites, while a mere four perish from the methods of agriculturists. In the next stage of development (for, like the frog, the corn-borer goes through a series of changes before becoming adult), another one of the 200 perishes from parasites. When the adults emerge, another five die before they mate. Thus, out of the original 200 eggs, only four individuals are left to carry on the next generation.

The corn-borer is connected with its surroundings in various ways. First, there is a bond between the animal and inanimate nature, whose raw materials (like *oxygen*) are necessary to the borer's life, yet whose climatic rigours are inimical to it. Secondly, the borer is linked to other species: it feeds on corn, while it is destroyed by a number of parasites. Finally, corn-borers compete and co-operate among themselves: their food-supply may be a matter of rivalry between them, but their reproduction depends on their co-operation. In short, a single corn-borer is related to the world in three directions—to inanimate nature, to other species, and to other corn-borers. And in each connection there are contradictory parts. On an historical scale, these types of contradictions provide part of the driving forces of evolution. Living material from time to time alters itself: a change occurs in a gene, a nucleus is rearranged, or two species cross. If the new creatures are better than the old at solving the contradictions of being alive, they survive and multiply. They, in turn, create new conditions and new problems. Out of these opposed necessities, by the survival of successful types, the living world develops and new species are created.

Life depends on inanimate nature. A plant cannot grow unless it is supplied with such chemical elements as *oxygen*, *chlorine*, *carbon*, *hydrogen*, *nitrogen*, *potassium*, *calcium*, *sulphur*, *iron*, *manganese*, and *phosphorus*. It is the need of plants and animals for quantities of some of these elements, like nitrogen and phosphorus, that is satisfied by the use of chemical fertilisers. In animals, there is the same dependence on inanimate surroundings. A herring, or a one-celled Amœba from the sea, cannot live in air or even remain alive for long in pure water. The cells inside the body of a warm-blooded animal are particularly dependent upon their surroundings. Yet, given suitable conditions, the cells of a bird or a mammal can be kept alive independently of its body. Some cells taken from a chicken in 1912 have been kept alive in America to this day by the French-American physiologist, Carrel. Since being taken from the chicken, they have divided many times and have passed through more than 4,000 generations. The conditions necessary to keep the cells alive give us an insight into their fundamental requirements. The cells have been kept in a solution containing a careful balance of half a dozen different salts and some sugar. To this has been added juices taken from the embryos of chickens. This juice stimulates the division of the cells. The liquid bathing the cells has to be frequently replaced by fresh liquid. In addition to needing a supply of these liquids, the cells need to have access to the oxygen in the air, to be maintained at a warm temperature, and to be protected from microbes.

The cells inside a large plant or animal are guarded by the outer wall of the body and they are bathed by the blood or other fluids inside the body. These fluids carry requisite chemicals to the living material and take away the waste by-products of life. The necessary chemicals are obtained from the outside world and the waste products are excreted into it. This means that the animal or plant must be in constant communication with the inanimate world. A rabbit, for instance, is in contact with the world in several areas of its body: air penetrates its body through its lungs; light pierces its eyes; sounds enter its ears; heat is exchanged between its body and the surroundings; food is brought into contact with its body and is absorbed in its intestines; waste products are shed via the kidneys in urine.

Living material must be connected with the world; it must also be separated from it. Some of the forces of nature are continually levelling things down. A lump of sugar, dropped into a cup of tea, will slowly spread all through it. In the same way the substances of an animal living in a pond would be dispersed throughout the water, were they not held in by the animal's skin. A rabbit would become as cold as its surroundings, if it did not keep its own heat in with fur. When a plant or animal dies, this levelling down does happen: material that was alive is dispersed, and a warm body goes cold. Living forms must be connected with the world to live, yet they must isolate themselves to preserve their life. The evolution of creatures has been towards improving the compromise. An Amœba is naked and exposed: a rabbit presents a wall of fur and skin to the world, and absorbs the material it wants in special enclosed regions, like the lungs and the intestines.

But a living being is not only connected with its inanimate surroundings: its existence is interlaced with the lives of other creatures. In the last chapter, the living world was divided according to differences in size and structure. There is another fundamental division which cuts right across those. On the very practical issue of how living beings nourish themselves, there are found to be two great groups—the producers and the consumers. The producers are the plants and the green, or blue-green, one-celled forms. The plants are mostly green, but some seaweeds are red or brown. With the exception of a few of the one-celled forms, the producers are stationary. They stay still and, by the action of light, they build up inside themselves, from simple raw materials, the substances which are food, both for themselves and for the consumers. The consumers are roughly of two types. There are the ordinary animals, including man, which eat plants, or which eat animals which eat plants. Though cows produce milk and bees produce honey, both are classified here as consumers, since they live on a vegetable diet. These animals shade into the type which lives in the body of other beings, like a tape-worm or some sorts of microbes. By a further step we reach the consumers which live by making the dead bodies of plants or animals decay. Taking part in the series of processes which go on in decay, are mushrooms, moulds, yeasts, microbes, and various other beings.

The relations between consumers and producers make an intricate network. Plants on land and one-celled plant-like creatures, called *diatoms*, on the surface of the sea build themselves up and multiply. Animals, like grazers on land and some small surface-species in the sea, eat them; other animals eat the vegetarians; and so the process goes on. There is finally a backward movement, when the decayers, settling on the dead bodies and on the waste, convert them back into the simple chemicals from which they had originally come. Man takes a more and more dominating part in this chain, as he becomes aware of the forces at work and bends them to his own purposes.

Smaller and smaller cycles of relationship occur within the main chain. Every big animal has one or more parasites, living on its surface or inside it and feeding on the excess of what it eats. A survey of one important human parasite has already been given in this chapter. In other spheres, different species co-operate together, as when insects secure the pollination—or fertilisation—of plants, while the flowers supply food to the insects.

As a result of the survival of the most suited types, the interaction between one species and another produces new forms of life. The process at work can be particularly clearly seen in the interaction between a parasite and a host. A case is provided by a guinea-pig whose blood is infected with the single-celled parasite called a Trypanosome. When the parasite enters the guinea-pig, it multiplies in the blood, and makes its host ill. While this is happening, the guinea-pig's blood elaborates a chemical which is very poisonous to the parasites. This chemical kills nearly all of them, and the guinea-pig's health improves. But a few Trypanosomes, particularly resistant to the poison, survive in their host's blood and multiply into a new strain of parasites, which cause a relapse or recurrence of the illness. The guinea-pig proceeds to build up a new poison deadly to the Trypanosomes, and kills most of the second strain. But a few again escape and procreate an even stronger race of parasites. Thus, in a series of recoveries and relapses, the blood of the guinea-pig becomes changed; at the same time the nature of the Trypanosome race is transformed. But the end is soon reached. Either the guinea-pig elaborates a poison which kills all the parasites, or the Trypanosomes multiply enough to kill their host. If the guinea-pig survives, its blood is resistant to this type of parasite; if the Trypanosomes survive by being transported to a new host, they may be unusually virulent.

A somewhat different interaction between species is that between insects and flowers. Bees, butterflies, etc., obtain food from flowers in the form of pollen or of sugary nectar. Flowers are cross-fertilised by insects carrying the pollen grains (which contain the male nucleus) from one flower to another. The interaction between insects and flowers has produced, on the one hand, bees and butterflies with mouths and limbs suitable for reaching and enjoying the nectar or pollen; on the other hand, it has produced flowers that attract insects by their radial shape and markings, their colour, and smell, and which shed their pollen on to the insects' bodies. It is not surprising that we find flowers beautiful, since they have evolved to attract animals.

The third type of interaction, that between individuals of the same species, has also played a part in modifying the nature of living beings. On the one hand there are " forces of repulsion " between individuals, generated by competition for food, light, or air. On the other hand there are forces which attract individuals together. One of them is sex. Offspring are born to those who can find a mate; so that there is a tendency for animals to develop methods of association for sexual purposes. These may be attractive colours, shapes, or smells, like the colour and form of the peacock, and, presumably, the smell of the musk-rat. Social life in many animals begins with the family. Since the force which opposes the association of animals is the competition for food-supply, we may expect family and social life to develop most commonly in the animal kingdom among creatures whose available food-supply is large. Many social animals, like the white-ants—or *Termites*—and beavers, which both feed on wood, and herds that graze on grass, have a particularly big food-supply. A full solution of the contradiction between the needs for association and those for separation is found when food is produced by co-operative effort. This is the case, above all, in human society. At this point, little more will be said about human society, which is discussed in the last part of the book. It is worth noting, however, that the communities of insects, like bees, wasps, ants, and termites, are really nothing like our society at all, notwithstanding the fact that their members have been called kings, queens, soldiers, and workers.

CHAPTER X

MIND AND MATTER

" It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us."

CHARLES DARWIN in *The Origin of Species.*

WHAT ARE THE FEATURES of the material whose mode of existence is life? According to Bayliss, the living material of an Amœba " appears, even under the highest powers of the ordinary microscope, as a clear, colourless, jelly-like stuff, not showing any structure, but nevertheless keeping itself distinct from the fluid surrounding it, not mixing therewith, and also capable of changing its form in response to changes in its surroundings."

One of the salient features of living material is that it is in a continual state of chemical movement. What is chemical movement? It is the building of chemical compounds, and their destruction. Generally a chemical can both be built up and broken down. Consequently a continual chemical ebb and flow takes place in living substance. Though its contents are moving in this way, a body keeps its external form. While the body of a tree is stationary and solid, chemicals are being rapidly created and destroyed inside its cells, their cytoplasm streams slowly round, sap mounts the trunk, and chemicals move up and down the height of the tree. Nothing in an animal's body seems more rigid than a bone; yet news came in 1935 from Denmark that a bone is in constant inner motion. A particle of the chemical element phosphorus, which is a chief constituent of bone, need not

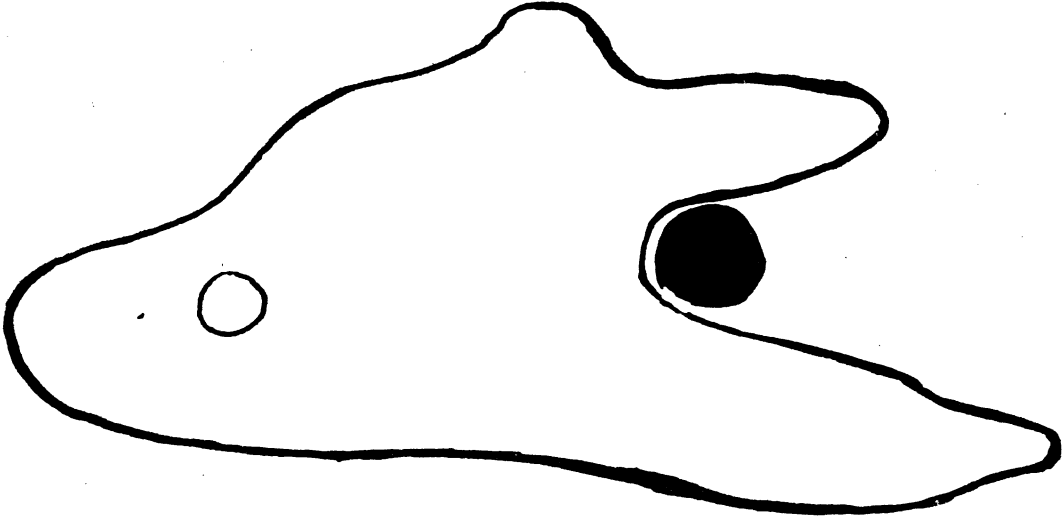

FIGURE 7. Amœba, flowing from left to right of the diagram, meets a small obstacle. The black circle is the obstacle; the uncoloured circle inside is the Amœba's nucleus. (After Jennings.)

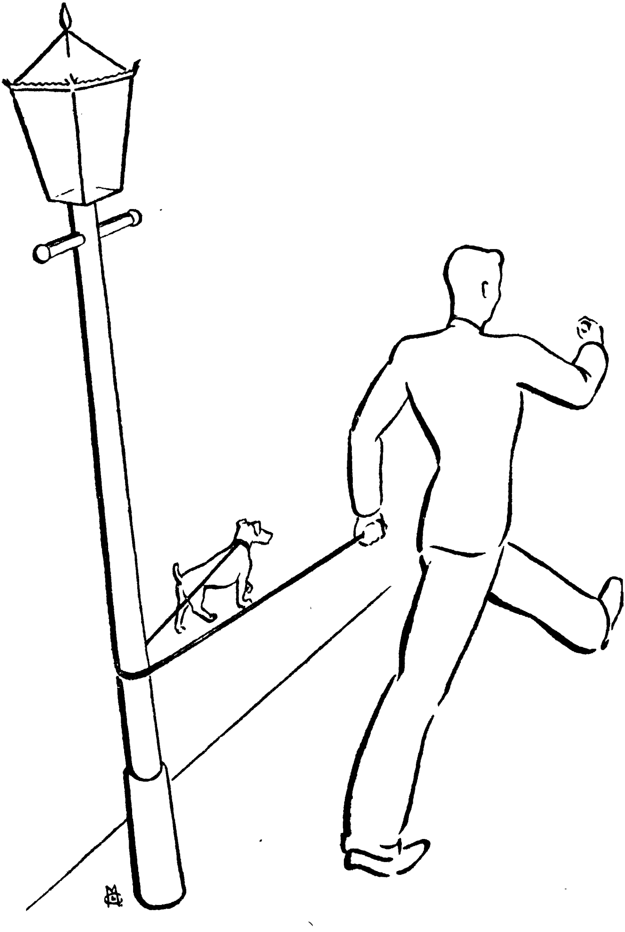

FIGURE 8. A man and a dog in the same situation as the Amœba in Figure 7.

stay in a living rat's bone for more than two months. Bits of phosphorus are continually entering and leaving it, though its shape remains unchanged. The ebbs and flows of chemical movements in living substance are intricately balanced. Because any slight event may upset these balances, living material is infinitely subtle and sensitive. Even an Amœba draws itself together if it is touched. In animals higher than Amœbæ there are elaborated specially sensitive cells called nerve and sense cells. Nervous material is poised even more finely, and responds even more acutely than the nerveless substance of other cells. As little as one ten-millionth part of an ounce of the odorous chemical *mercaptan*, mixed in the air of a room 11 feet by 13 feet by 15 feet, can be detected by the human nose. A state of excitement can hurtle along a dog's nerve, from its limb to its spinal nerve-cord, at 30 yards a second; having reached the spinal nerve-cord, the excitement can be quelled by the opposing force of *inhibition* inside a fraction of a second. The tenderness of a snail's horn, the keenness of an owl's sense of sight, the retentiveness of human memory, and the nuances of our emotions are all expressions of the infinitely subtle balances possible in nervous material.

The creature Amœba sometimes gets itself in a situation which reveals the poise within living material. Amœba moves by flowing over the ground; it flows forward and draws itself up behind. Sometimes, while it is thus flowing along, it meets a small immovable obstacle and flows on to both sides of it. It is then in the same situation as a man going along with a dog on a lead, when the dog walks on one side of a lamp-post while he walks on the other side. In circumstances like this, Amœba takes a " decision." One branch of the body is drawn back, the other is pushed forward, and the whole creature flows forwards on one side of the obstacle.

The slow historical development of life itself has produced the sensitiveness of nervous material. To a man in a bare world, empty of living beings, his senses would have little meaning except to help him avoid poisons and precipices, to enable him to keep his balance, and to travel in a straight path. In a world peopled with living beings the qualities of nervous material are applicable to catching prey, to avoiding being caught, to sexual relations, and, above all, to the use of tools and to social communication. The higher levels of animal behaviour have come out of relations with living beings. The division of animals into hunter and hunted, the keeping together of individuals to make societies, and the use of tools have created the conditions in which mind was born and has grown.

Subtle and complex as it is, mind is part of nature. Thinking is part of the activity of the brain; the brain is the most complex form of nervous tissue. Therefore, even the subtleties of thought and feeling are dependent on the material condition of the brain. Human thought is affected by minute quantities of certain chemicals. Guttmann and Sargant have just reported that one two-thousandth part of an ounce of the drug *benzedrene*, when swallowed, increases a man's confidence, initiative, and ease in making decisions, and speeds up the thinking process without impairing attention, concentration, or judgment. The list of other chemicals which, even in small quantities, affect the human mind is very long. Some are drugs manufactured by chemists or extracted from plants, like chloroform and caffeine; some are the poisons produced by microbes; some of these chemicals are made in our own bodies in small quantities and help to govern our behaviour. The action of all these on thought is only possible because the mind depends on the activity of nervous tissue; and the nervous tissue of the brain is in a highly refined state of chemical balance, which is thrown out by minute quantities of chemicals applied to it.

The animal kingdom presents us with different levels of the organisation of nervous tissue. There are one-celled forms without nerves; there are primitive animals with a simple network of nerve-cells spread over their bodies;

better organised animals exist in which the nerves are concentrated into a cable of tissue, known as a nerve-cord; and there exist advanced animals in which the front end of the cord is elaborated into a brain. Along with this development of nervous tissue has come the appearance of thinking. But it is not worth while making detailed guesses at the origin of thought until the way the mind works is better understood.

There is every reason to suppose that living material, in the remote past, was born out of inanimate matter. It has lately been estimated that more than 900 million years ago the slow building up of inanimate chemicals culminated in this unwitnessed birth. If living material was born as sub-cellular particles, then the next step was the association of particles into cells. A guess can be made at what happened to a succession, or a stream, of living cells once it was in existence. The stream began to break up into streamlets. In each streamlet a different aspect of the fundamental qualities of the living substance was emphasised. In one, the powers of building up substances were specially developed; this streamlet was the beginning of the plant-forms—the producer branch of life. In another streamlet the powers of utilising built-up substances were accentuated. This was the streamlet of consumer-types. The first of them were probably decayers. Members of the two streamlets interacted on each other from the start. The decayers knocked over the ladder by which all forms had climbed. They destroyed the built-up chemical substances out of which living material had been born. With the destruction of these substances the possibility of a re-birth of living material out of inanimate matter vanished. Continuing to apply the principle of interaction, we can make further guesses. If cells were developed from sub-cellular living particles, then the decayers would destroy these too, or their food. But some particles might survive as parasites on the cells. Like a boxer, the sub-cellular particle, going into a clinch, as it were, with the cell, could not be hit. These parasites would be represented to-day by viruses.

New forms, which could cope with contradictory situations better, were selected. These new forms themselves created fresh conditions, and thus made more opportunities for change. Grazing animals, for instance, must have evolved side by side with grass. Grazing favours the growth of grass, because it damages other plants more than it hurts grass. Grazing animals, therefore, enable grass to spread by destroying its plant rivals; and the animals are able to thrive in turn on the grassy plains which they have helped to produce. Later in history, grass provided man with his main crops—wheat, barley, maize, rye, oats, and hay. The whole process is one of division and interaction. It has produced living creatures with new qualities; it has produced living material that can think; it has produced man.

PART III

Biology Used and Misused

CHAPTER XI

FOOD AND CLOTHING

MANKIND lives on the backs of other creatures. Timber, paper, artificial silk, turpentine, rubber, linseed-oil, rope, alcohol, soap, and some drugs and explosives, as well as food, and linen, cotton, and woollen clothes, are the products of the living world. Also is man indebted to long-dead plants and animals for the bases of chemical industry, lime, coal, and petrol and their derivatives; but the techniques of working these are not biological, and they do not concern us here.

Logically, the first branch of biology should be the science of human needs. Without it, the live resources of the world cannot be efficiently utilised. But there is not yet a unified science of human needs; though preventive medicine and dietetics are the beginnings of it. During the last century, preventive medicine worked out the needs of the community in drainage, water-supply, and the protection of food from contamination. In the present century, dietetics has discovered nearly exactly the food requirements of a human being, and has thereby established one important and fundamental principle: people require a diet of a twofold nature.

A man, woman, or child requires some sorts of food in reasonably large quantities. These might be called the " bulk-foods." They supply the main material of, and the food for, the bodily machine. Comparing a man to an aeroplane, the bulk-foods of man correspond both to the metal of which the aeroplane is constructed and to the fuel that drives the engine. But bulk-foods are not enough; people die unless they get certain " extra-foods." Though these extra-foods are vital to health, only minute amounts of them are needed to keep the bodily machine in smooth-running order. Pursuing the comparison of the aeroplane, some extra-foods may be likened to the lubricating oil of the engine, others to the units from which the delicate navigating instruments of the plane are built.

Bulk-foods are of three main classes. Foods of one of these classes, called the *carbohydrates*, are the chief constituents of sugar and of the starchy stuffs like bread, potatoes, rice, and porridge. A second class consists of fats like dripping and butter, and of oils like olive oil. The third class is the " flesh-foods," or *proteins*, which come mainly from meat, fish, and eggs. Starches, sugar, fats, and oils provide the body with energy; they are the fuel of the body, corresponding to the petrol of an aeroplane engine. But the material of our bodies (except the bones) is largely made out of complex proteins. The proteins that we eat, therefore, are the raw material for body-building, and compare with the metal out of which an aeroplane is made. While adults require a certain amount of protein for repair work, children need a relatively greater amount with which to build their bodies. An eight-year-old child and a full-grown man require an equal quantity of protein—not less than two-and-a-half ounces a day.

A full investigation of the extra-foods required by man will be one of the major scientific achievements of this century. Some of these extra-foods are mineral elements like iodine, iron, calcium, and phosphorus. Without minute amounts of iodine in the diet, people develop the large swelling in the throat known as goitre. Iodine is present in the soil in most parts of the world, and the traces of it, entering the plants and animals of the farm, are sufficient to supply the iodine ration of the people who eat them. But in certain districts, in Ohio, Derbyshire, Switzerland, and in other regions, people are liable to suffer from goitre because there is no iodine available from the soil. To protect inhabitants of these areas from the disease, a tiny quantity of iodine must be added to their diet. A doctor found that one-seventeenth part of an ounce of iodine, given to each child, was enough to keep the children of Akron, Ohio, free from goitre for a year.

It is estimated that a human being requires a daily dose of about a two-thousandth part of an ounce of iron, a thirtieth part of an ounce of calcium, a fraction more phosphorus than calcium, and about one-fifth of an ounce of common salt, which contains the mineral elements sodium and chlorine. Lack of salt causes cramps. Miners working in warm pits lose a lot of salt by sweating, and need to eat quantities of it to make up the deficit. Some of them are said even to take salt in their tea to prevent cramps. A diet including a fair proportion of eggs, vegetables, fruit, meat, and milk contains sufficient quantities of minerals. Where the diet does not include these foodstuffs, bad bones and teeth, anæmia, and other debilities result. Sir John Orr calculates that the poorer half of the inhabitants of this country have insufficient iron and phosphorus in their food; and the poorest one-third suffer also from lack of calcium.[1]

But these mineral elements are not the only necessities, in the way of extra-foods, which man requires. There are also the vitamins, of which at least six essential to life have been distinguished. The lack of any one vitamin causes in the body a particular defect which may be so serious as to result in death. The six are labelled: Vitamin A, Vitamin B1, a group of vitamins denoted by B2 (or G), Vitamin C, Vitamin D, and Vitamin E. The distinction between Vitamin B1 and the B2 group was discovered after the original Vitamin B had been labelled. This illustrates how the process of research goes on distinguishing more and more finely between the different substances necessary for life. Blindness or weakness of sight result from a lack of Vitamin A, a lack which is rare in this country, but common in Africa and India. The vitamin is obtained from animal fats, cod-liver oil, carrots, and greens. Vitamin B1 prevents a disease known as beri-beri, which is a kind of paralysis common among the people of the East who live almost exclusively on rice. Vitamin B1 is contained in the husks of grains, in yeast, liver, egg-yolk, and other foods. A deficiency in Vitamin B2 results in a fatal inflammation of the skin called pellagra; a disease from which seven thousand Americans died in 1930. This vitamin is contained in meat, liver, and yeast. Vitamin C, which is found in fruits and salads especially, prevents and cures the disease of scurvy which attacked sailors living on salt food. Vitamin D, with which the reader is already familiar, is the substance necessary to prevent rickets. It is found in cod-liver oil, liver, eggs, summer milk and butter; and it is made in our bodies by the action of sunlight. Vitamin E has been found necessary to rats to enable them to reproduce themselves; if a pregnant rat has been deprived of Vitamin E, it digests and absorbs the offspring in its womb. The facts discovered from researches in rats also apply to human beings. It has lately been proved that wheat-germ oil, rich in Vitamin E, can cure women who suffer from habitual abortion. The ultimate effects of each vitamin lack have been mentioned; the effects of lesser insufficiencies are weaknesses like bad teeth and gums, and liability to inflammation of eyes, skin, and throat.

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[1] *Food, Health, and Income*, by John Boyd Orr. Macmillan.

The new knowledge that human foods are of two types —the bulk-foods and the extra-foods—gives mankind far greater freedom in his diet problems. Up to the present, people have unconsciously obtained their extra-foods (except common salt) as small constituent parts of their bulk-foods. In working-class homes the diet often cannot contain the costly milk, meat, vegetables, eggs, salads, and fruits necessary to supply the extra-foods.

Just as the discovery of microbes in the last century played a profound part in the enormous improvements in town sanitation and water-supply, resulting in increased health, so the discovery of vitamins in this century can lead to a further general improvement in the well-being of the population. This can be done by supplying free, or cheaply, the necessary " luxuries " that contain vitamins. A recent and as yet unpublished inquiry in Belfast tends to show that the need for a diet rich in vitamins is understood even in the poorest homes. Budget *questionnaires*, asking families " What would you do with an extra 5*s*. a week ? " were very commonly answered, in a group that included many people with less than five shillings a week per head to spend on food, with " I would buy milk, vegetables, fruit, fish, etc." If the purchasing power of the poor housewife is raised, we may expect, therefore, that she will supply her household with vitamin-rich food. Milk contains calcium, phosphorus, protein, good amounts of Vitamins B1 and B2, and Vitamins A and D in summer. Where children are given extra milk the results are sometimes extraordinary. They put on twice the weight they used to, their hair becomes glossy, their well-being strikes the eye, and their spirits are much higher. If winter milk is enriched with synthetic Vitamin D, its value is even more increased. Probably the simplest and cheapest step that could be taken to increase the health of the nation would be to supply free milk, enriched with the necessary vitamins, to everybody who cannot afford it. Another way of solving the diet question might be the creation of really reliable " vitamin sweets " and " vitamin sauces," with which children and adults could supplement an otherwise inadequate diet. The staggering effectiveness of vitamin-rich foods in preventing death and the huge extent of the need for them were brought out at the 1937 meeting of the British Medical Association. A doctor described how, in 1936, 7,000 expectant mothers of Durham and South Wales were given every month parcels of vitamin-carrying foods. This simple

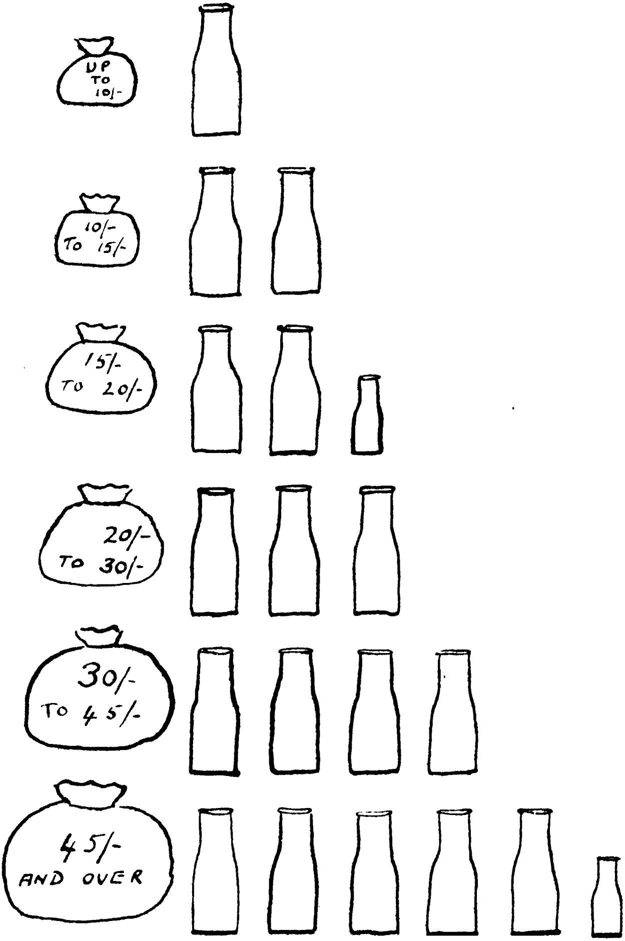

FIGURE 9. The average weekly consumption of fresh milk in the United Kingdom by people with various incomes. The figure on the money-bag indicates the income per head per week. The large bottles represent a pint of milk, the small bottles a half-pint. (Statistics from Orr.)

measure reduced the maternal mortality rate among them by 83 per cent !

After the study of human needs should come the investigation of the general economy of food-production. Though continual improvements in farming are being made in various directions, thorough studies of the total system of food-production are only beginning. For example, some of the most expensive of the bulk-foods to produce are the proteins. The most expensive proteins, those in milk, meat, and fish, are by far the most nutritious. How is the supply of proteins to be efficiently augmented ? Obviously meat, fish, and milk must be retained as foods; but extra proteins might be got from more peas and beans, and, in the more distant future, perhaps from moulds and yeasts. Without research on a large scale such a problem cannot be dealt with.

In particular fields and in many ways biological research has begun to indicate new economies in production. The number and variety of the new discoveries suggests that we are on the verge of an Agricultural Revolution. The traditional methods of exploiting living species are being improved on and replaced. Fields and forests are being brought under control by the engineers who build farm machines, by the chemists who extract or manufacture fertilisers, by the breeders who create better varieties of stocks and crops, by the parasitologists who turn one species against another so that man and his crops are left free, and by the biologists who can state the best climatic and chemical conditions for the growth and well-being of living things. The three branches of biological knowledge which are chiefly working this change may be numbered:

(1) The science of genes.

(2) The natural history of parasites and pests.

(3) The study of the relations of climate and chemicals to the growth and well-being of living things.

The new knowledge of genes' behaviour enables breeders to pack into a single race the desirable hereditary qualities of many. Qualities like a plant's resistance to disease, its yield of fruit, its rate of ripening, and the cooking, milling, and dietetic value of its product, are all carried from one generation to another by genes. The breeder's problem, which is solved more and more efficiently as years go on, is to combine the requisite genes. He is often able to extract a disease-resisting pair of genes from a wild cousin of his crop-plant. He is able to obtain the other qualities from different cultivated varieties, or from new mutations. One of the great achievements of these methods has been the pushing of Canadian wheat ninety miles northward. New varieties, like Garnet, that ripen faster than the old-fashioned Red Fife wheat, have enabled the extra miles to be covered. When all crops have received the same attention from the breeders as has wheat, the agricultural potential of the world will be raised to a higher power.

The resistance of a plant or animal to parasites that cause disease is hereditary: it can also be stimulated by artificial means. The resistance of an animal to a microbe, for instance, can be developed by purposely infecting it with weakened or dead microbes or with microbes of a related, but less deadly, race. These excite the infected body to produce chemicals that kill the microbes and protect it from further invasions. This principle of vaccination, as it is called, has been much used in human and animal medicine, and it is now being applied to plants. Dr. Salaman of Cambridge has just reported success in vaccinating potatoes against the Y virus which attacks them. To achieve this, he weakened the virus by allowing it to live first in a tobacco plant.

The science of parasitology gives us several other weapons against parasites like viruses, microbes, Trypanosomes, and blood-flukes, and against the weeds and insect pests that deplete the yield of crops. Probably the most labour-saving method is to set one species against another. The prickly-pear, a cactus weed of Australia, is now being eaten away by the moth *Cactoblastis,* which was introduced to remove it. The parasite that causes the scab disease of potatoes goes under the name of

Actinomyces scabies. It lives in the soil, and from that vantage point it infects the potato. But, if a near-related species called *Actinomyces præcox* is introduced into the soil, it suppresses the action of *scabies* on the potato.

Without using an antagonistic species against them, some parasites can be destroyed by well-informed frontal attacks. If a person is infected with a microbe disease, he is isolated. Whether he then dies or recovers, the microbes in him perish without being able to plant their offspring in anyone else. If a parasite lives alternately in one species and then in another, it can be eliminated by getting rid of one host. Species of mosquitoes, rats, lice, and water-snails are hosts of parasites which attack man as well; and the barberry is a shrub which harbours the rust parasite of wheat. Destroying these species is easier than destroying the parasite directly. The mosquito that carries yellow-fever passes part of its life in standing water. It can be eliminated from a town by carefully draining or covering all puddles and pools in the neighbourhood.

The human war with pests and parasites is a dynamic and sometimes a paradoxical process. One parasite may weaken the resistance of its host to the attacks of a second; another may strengthen its host's resistance to a second species. Patients suffering from general paralysis of the insane, due to syphilis in a late stage, may be cured by infection with malaria. The fever kills the syphilis parasite by overheating it. Where a pest is introduced into a new country, agricultural methods are not adapted to cope with it and its natural enemies are not present to keep a check on it. Consequently it spreads like wild-fire, as was the case when the European corn-borer was taken into America. This invasion is being met by a change in American farming methods and by the introduction of parasites that destroy the corn-borer. When a parasite is of the kind that can kill its host, then between the host and the parasite there is a swinging balance. If the hosts are many and unprotected, the parasites multiply. They reduce the numbers of the hosts by their attacks and then they themselves starve because they can find no new hosts to live on. The parasites therefore become greatly reduced in numbers, and the few remaining (and particularly resistant) hosts are able to spread again. So there goes on the same sort of struggle as that which occurs between the guinea-pig and the Trypanosome (Chapter IX). Out of this struggle come changes in the species of both the attacker and the attacked. Parasites can and do change their habits and their constitution; but, since man's inventiveness works faster than they can alter, we can expect only one final outcome of the struggle—the complete elimination of species harmful to man. The rust parasite of wheat has produced many new mutations in recent years capable of attacking hitherto resistant wheats; but the new wheat Hope (Chapter VII) is immune to them all.

Growing creatures are extremely susceptible to climate and chemicals. Each crop requires its own climatic and soil conditions. Up to now, irrigation, land-drainage, and the hot-house have been the main methods available for controlling these conditions. Lately, supplying crops with an " artificial climate " has become a practical possibility. The seeds of winter wheat are normally sown in the autumn; they lie in the soil through the winter and grow in the spring. Spring wheat, on the other hand, is sown in the spring and can therefore be used in those climates whose winter damages wheat seeds in the soil. Winter varieties of wheat have a higher yield than spring varieties, and it would be advantageous to grow them where at present only spring varieties can be grown. Winter wheat seeds can now be provided with a controlled " artificial winter " in the laboratory. After being thus *vernalised*, as it is called, they can be sown in the spring and a crop of winter wheat can be harvested in due course. The ripening of apples and pears is likewise affected by the " climate " in which they are stored. By keeping these fruits in the correct atmosphere of *carbon dioxide* and oxygen gases, at a coolness just above that of melting ice, their storage-lives can be prolonged many months. In this way supplies of fruit can be spread over until the following harvest. Plants and animals need, as man does, calcium, iron, phosphorus, iodine, manganese, nitrogen, and other elements. Without an adequate and balanced supply of these chemicals in the soil, several things may go wrong. A crop may suffer from "deficiency disease": when oats are grown in a soil which does not contain a trace of manganese, their leaves come out in grey blotches and the plants die prematurely. Where other elements are lacking, the growth of the crop may be retarded and the plants rendered susceptible to parasitic infection. Even if these things do not happen to the crops, the cattle that feed on them may be damaged. For, while the plants may contain enough iron, calcium, phosphorus, and iodine for their own needs, they may still not contain enough minerals to supply the requirements of the cattle. Accurate chemical and physical analysis of the soil is a preliminary to its best exploitation.

More complicated chemicals than the elements mentioned above also affect the growth, health, and behaviour of living things. Substances of this type include the various drugs, vitamins, and *hormones*. Hormones are produced by the body and they have a definite effect upon it. The hormone *insulin*, for example, is produced by, and circulated through, the bodies of all healthy people; and it controls the sugar-economy of the man. When the production of insulin dries up, as occasionally happens, the body suffers from the disease known as diabetes. Hormones which affect the growth of plants have also been discovered; and the chemist can make substances which have a similar action. Some of these synthetic hormones stimulate the growth of roots, and one of them has just been put on the market to help gardeners in making their cuttings grow roots. A further knowledge of hormones may later give aid in controlling the grafting of plants, the egg-laying of hens, and the milk-production of cows.

This account has indicated the actualities and the possibilities of the new methods of biological control. We are in sight of widespread improvements, and there is no immediate limit to the amount of food and clothes that man can produce if he wishes to.

CHAPTER XII

OVER-POPULATION

ARE THERE too many people in the world for the available food supply? Will the increasing population outgrow the food supply? These two vital questions are put in the pessimistic form we inherit from Malthus and his friends. Alternatively, bringing the horse to the front of the cart, we may repeat the questions from the human point of view. Is there, or can there be, a large enough supply of food, clothes, fuel, houses, books, films, and other goods for everyone to be adequately equipped? Can there be in the future a sufficient expansion of supply to meet an increasing population? These are questions on which the public are entitled to be fully informed, and biologists can take a hand in supplying some of the facts.

Our natural approach to such questions is to look at our own experience first. We in Great Britain, which is reckoned a prosperous corner of the globe, notice around us, or are experiencing, unemployment (the number of unemployed varies between one and two and a half million), undernourishment (Sir John Orr calculates that the diet of about half the population is below the proper standard), and long-standing overcrowding in most large towns. We come quickly to a conclusion—*there are too many people.* When we learn that between 1850 and 1930 the population of the whole world doubled itself, rising from one to two thousand millions of persons, our first conclusion is more firmly established in our minds. We decide that *the world is over-populated.*

But our conclusion is badly shaken if we look at the world from the less usual angle, if we turn to scrutinise production. The land area of the globe is 33 thousand million acres, and this area was estimated by Dr. A. E. Taylor in the 1929 *Encyclopædia Britannica* to be capable of supporting 6 thousand million people—three times as many as the existing population. This is disturbing enough to our theory, but other facts break it up entirely. We discover in post-war records a dreary list of cases of "over-production." Coffee is burned in Brazil; herrings are dumped into the sea in English ports; excess calves are slaughtered in the Irish Free State; surplus pigs are similarly treated in the U.S.A.; tobacco and cotton crops are ploughed up in the U.S.A.; rubber is restricted in Malaya, and so on *ad nauseam*. We read of even more drastic proposals. Professor H. T. Fernald, the American expert on agricultural insects, writes in 1935 that:

"Still more recently the value of controlling insects injuring crops of which an excess has been raised, leaving a surplus which cannot be disposed of, has been discussed and the proposal made that attacks of insects on such crops should be allowed to proceed unrestrained to reduce or entirely prevent any surplus."

It is argued that, while damage to crops by pests will reduce the food supply, it may help the producer by introducing scarcity and raising prices. The pros and cons of this argument are outside the province of biology; but on the here-and-now possibilities of agricultural production, biology can shed some light. Clearly the first question bearing on "over-population" is this: Can production be expanded at short notice so that, if present potentialities were utilised, there could be adequate supplies for all people alive to-day ? In the opinion of the experts of the International Institute of Agriculture it can be expanded, as the following statements show:

"It would scarcely be an exaggeration to say that the world's food production could be increased many times without increasing the area of cultivation, if mankind exploited to the fullest extent all the scientific knowledge now available."[1]

" In view of the modern conditions of agricultural knowledge, the possibilities of agricultural production are very great. Taking the world as a whole, the limits of these possibilities may be practically left out of consideration altogether. With regard to individual countries, with the exception of certain regions which are undoubtedly over-populated in relation to their productive capacity, such limits are generally far from being reached."[2]

These sound very large claims for the experts to make, but even the single step of using all over the world the biological inventions which are at present being used in small areas would markedly expand production. Three cases illustrate the point. As a result of five years' intensive research into the breeding of the sugar-cane in Java, Dutch biologists have produced a new, high-yielding strain. Sir Daniel Hall[3] states that this has raised the yield of Javan sugar-canes to 6 tons to the acre. If the Javan production level were applied to all sugar-cane, the world production of cane-sugar would be more than doubled, for the average yield of sugar throughout the world is less than 1½ tons to the acre. A great rise, though a less spectacular one, might be obtained with wheat.

Dr. Charles writes:

" The Cambridge School of Agriculture, under normal working conditions, consistently obtains a yield of 60 bushels per acre of wheat, as compared with an average of 32 for the whole country. The low average of English wheat as compared with Danish is attributed by the 1921 Commission on Land Drainage to water-logged soil, a handicap which could be remedied by collective action.

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[1] Quoted in Quarterly Bulletin, League of Nations Health Organisation, 1935.

[2] Quoted in Report B23, International Labour Office (League of Nations.)

[3] *The Frustration of Science: A Symposium.* Allen & Unwin.

Even so, the average yield for English wheat is high compared with that of Oriental and Mediterranean countries."

The introduction of clover and turnips in rotation with corn raised the yield of wheat in England from around 10 bushels to the acre to about 20 in the eighteenth century. The introduction of artificial fertilisers and the improvement of land drainage in the first half of the nineteenth century again increased the yield in this country from 20 to 30 bushels to the acre. In Southern Europe and Northern Africa the yield of wheat to-day is from 10 to 20 bushels to the acre. There is no doubt that, where wheat is grown on small or medium-sized farms, its production could be greatly increased by measures raising the yield of the crop on land already in use.

A third discovery which could be applied with like results was made about grass by English agriculturists during the last decade. If grass is mown when the shoots are young, and dried artificially, the product has a much higher food value for cattle than has ordinary hay, which is cut when old and dried in the sun. Moreover, many more crops of grass can be cut each year. Hay is a very important crop; it is one of the four major crops of the United States. If this invention were universally applied to haymaking, the world production of meat could be greatly increased. These three cases show what might be done immediately in only one direction. Taking into consideration the very numerous other methods of improving agricultural output, it would appear that the experts' estimates are perfectly sober ones.

Something has already been said in Chapter XI of the wider possibilities of biological invention. The 20–25 per cent loss of crops to pests could be eliminated; tropical and desert land and land in cold climates could be brought into cultivation. If it were made possible for wheat to grow yet another mile further north, several thousand square miles of land could be added to the world's three hundred thousand odd square miles under wheat. The creation of wheat that would grow up from the same roots every year would multiply the number of grazing animals which could be raised. The possibility of doing this by crossing wheat and wild couch-grass, appears to be already in sight. The threat of a world famine in the element nitrogen, which is so important for crops, has already been banished; chemists have invented means of tapping the air, the world's largest nitrogen reservoir. These few illustrations indicate some of the facts which led the experts to conclude that " the limits of these possibilities may be practically left out of consideration altogether." Hence, even if the world population expands faster than its present rate, biological invention will be able to cope with it.

But the startling thing is that the populations of many countries, like those of North America and those of Western, Northern, and Central Europe, are ceasing to grow, and are expected by experts to decline in the near future. The peoples of Great Britain, France, Germany, and Austria are estimated to be at, or near, their greatest number now, and to be about to decline in number unless there is a radical change in their ways of living. The people of Italy are still increasing, but in about thirty years time a decline in their number may well set in. The cause of this event, which seems to be affecting the centre of Western European industrialism, has not yet been explained, but it must be very deep-rooted. Efforts which have been made to increase the population, by raising the birth-rate, in Belgium, France, Germany, and Italy have not been effective. It seemed in 1935 as though the Nazi government's marriage loan scheme, started in 1933, had stemmed the rapid decline in the numbers of the German people. But the figures which came in for the end of 1935 showed that the temporary improvement was vanishing in a reappearance of the old decline. A loan of up to one thousand marks for purchasing household goods is made by the government to couples getting married. No interest has to be paid on the loan, and the full sum has to be repaid at 1 per cent per month. A quarter of the original loan is given to the couple on the birth of each child. As a result of this, the birth-rate in the main towns of Germany rose from 13 children being born among every thousand people, in January 1934, to 15 children being born among every thousand people in December 1934, and to 16 per thousand in January 1935. But this spectacular rise was capped by nearly as great a fall. By December 1935, in the large towns of Germany, only 14 children were born among every thousand people.

The phrase " over-population " has little useful meaning for ordinary purposes. In the first place, there certainly is overcrowding, unemployment, and malnutrition; but this is not because the world has reached the limits of its productive capacity. Secondly, there is no connection at all between the unemployment in a district or country and the numbers of the people there. In some of the country districts of Scotland, where in each square mile of land there are very few people, there is the highest degree of unemployment in the country—higher even than that of the thickly populated Clydeside. In Canada, in 1932, there were on an average less than eight people to every square mile of *habitable* land, yet over 2 per cent of the population was unemployed; while in France in the same year there were about 190 people to the square mile, yet less than 1 per cent of the population was unemployed. If unemployment were due to there being too many people in a country, how, again, is the fact explained that in many countries, while the population remains practically the same, the percentage of unemployment may double or halve itself in a few years? While the population of Great Britain changed little between 1929 and 1934, the percentage of workers unemployed rose from 8·2 per cent in 1929 to 17·6 per cent in 1932 and fell to 13·9 per cent in 1934. Professor Carr-Saunders, in showing that unemployment is not due to " over-population," uses the comparison of an inefficient steam-engine to explain the nature of unemployment:

" The nature of unemployment in general may be illustrated by an analogy with a steam-engine in which the steam introduced is the man-power. If the engine is working badly a lot of steam will escape and remain unproductive; this is unemployment. If we reduce the amount of steam entering the engine without improving the mechanism, we may very slightly reduce the amount that escapes; but, however little is introduced, a large proportion will continue to escape. In other words, if we reduce the population without removing the causes of friction in the industrial machine, we shall still have unemployment, though perhaps not quite as much."[1] The conclusion we first jumped to, that there are too many people in the world, is wholly unscientific. Unemployment is the steam escaping unused from a primitive social engine. Continuing the comparison further, we might liken the potentialities for increasing agricultural production to large supplies of coal available for the engine, which cannot be used because the boiler would burst.

CHAPTER XIII

WAR

IT IS OFTEN HELD that biology can explain why states go to war. If this is true, it adds much to the value of the science, for to understand the causes of war is the first step towards controlling it. Even if science showed that war was due to certain tendencies in human nature, the case would not be hopeless, for human nature might be suitably altered. It is therefore worth while examining in a clear light the various theories of the causation of war which are of a biological type.

But perhaps we may save ourselves the trouble. For it has been argued that war is biologically valuable, and that battles between states improve the human species. If the statements to this effect found in some writings were crystallised into one argument, it would run thus:

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[1] *World Population*, A. M. Carr-Saunders. Oxford, Clarendon Press.

The side that wins a war consists of the cleverer or fitter races or nations. After winning, they multiply more than the losers, and so the earth becomes peopled with the better race at the expense of the less good.

Does war, even at the cost of killing the fittest human beings, benefit the species by ensuring that the fitter race or nation multiplies more than the less fit? If this does occur, we may expect the birth-rates of England and France to have risen, or not to have fallen, after the Great War. At the same time the German birth-rate would fall greatly; and the Swedish would be unaffected. What are the birth-rates before and after the War?

Years	*England & Wales*	*Germany*	*France*	*Sweden*
1911–1914	24·1	27·4	18·6	23·5
1930	16·3	17·5	18·0	15·4

The birth-rates of all these countries have fallen. England, Germany, and Sweden have fallen together, while France has dropped slightly from its earlier low level. The populations of these countries, whether victor, vanquished, or neutral, are all expected by the experts to decline in the near future.

The idea that modern war improves the species is fallacious. Since war does profound damage to mankind, it is incumbent upon biology either to put forward a clear explanation of the cause of war, or to state equally clearly that it cannot explain its causation.

Two theories of a biological nature have often been used to explain the cause of war:

(1) War is due to some innate tendency, or instinct, of human beings.

(2) War is caused by the pressure of surplus populations.

(1) It is argued in favour of the instinct theory that war is always with us, and therefore it must be caused by some inborn tendency in mankind. This tendency is variously described as " aggression," " sadism," " fighting instinct," " racial animosity," or " national antagonism." It is also often suggested that this tendency has been produced by the processes of struggle between species out of which mankind came into existence. Before going any further, it is worth comparing human warfare with the struggles of other living species. War is not a fight between one species and another, as when a lion destroys a buck, or a doctor poisons microbes with antiseptic, or a stockbroker shoots pheasants. War is also not a struggle between individual members of a species, like a human brawl, a combat of rutting stags, or the competition between dandelions. It is the conflict between organised societies or states of human beings. Therefore, the usual parallel drawn between human warfare and the struggles of animals is quite inappropriate. Warfare is an invention of man, and a comparatively recent one. Our species has not always waged war, and even to-day there are tribes of men who have never yet engaged in it. According to Dr. Havelock Ellis:

" There is not the slightest ground for supposing that the earliest men waged war. . . . What early man needed, and, as we know, made, were tools. Weapons came later, and even then in the first place it would seem for hunting.

" . . . If we turn to those still existing savages or uncivilised peoples who, though not truly primitive are doubtless nearer to early man than we ourselves are, it is the same story continued. Many have developed warfare, some of them, like the Caribs—and this is a significant fact—only in recent times, while to others it is still unknown."

Excavators of the Indus Valley civilisation, one of the oldest human cultures known, and the most advanced of the early ones, found tools in profusion. But they found only a few weapons (and these very ineffective in design) and no armour, nor battlements to the towns. In short, whatever the reason for human beings making war, it is not original sin.

The findings of scholars are amply borne out by the evidence of common sense. You have only to talk to a few people in a railway carriage to realise that their instinct for war is immensely weaker than their desire for peace. It is necessary for biologists, on these and similar grounds, to repudiate the theory that war is caused by man's " fighting instinct."

If war is not due to personal aggressiveness, is it caused by " racial animosity " ? Thomas Henry Huxley's idea of a race was that it consisted of a group of people whose appearance was readily distinguishable from other groups. Thus you would be able to classify into separate races a mixed crowd of Japanese and Zulus. Huxley distinguished two races in the British Isles, a fair race and a dark race. It was he who pointed out, when the Irish were demanding to be separated politically from England, that there were no true racial grounds for this separation; because the inhabitants of Ireland consisted of a mixture of the same races as did the inhabitants of England. A mixture of the same two races is also found in Scotland and Wales. Yet in the Middle Ages there were wars between England and each of the other parts of the British Isles; and in 1920 there was a miniature war between Ireland and England which resulted in the formation of the Irish Free State. There have also been many other wars, the English Civil War, the American War of Independence, and the American Civil War, where in each case members of the same race, or races, were fighting against each other. Conversely, there have been many historical cases of racial assimilation, like the union of Bretons, Normans, Basques, and other races in France. Clearly, then, it is not true to say that war is caused by " racial animosity."

If, then, " racial animosity " is ruled out, is war due to " national antagonism " ? Unfortunately the same objections apply to this as to the last theory; for the English Civil War, the American Civil War, and the present war in Spain (before the German-Italian invasion), and many other wars have all occurred within one state.

A scientific approach to the facts shows, therefore, that war is not an aimless brawl, springing from the pugnacity of the human heart; it is not caused by any of the various racial and national feelings of antagonism. The presence of pugnacious feeling in all wars, and of feelings of national antagonism in some wars, is explained by the fact that these emotions are the weapons of war. It is as necessary for a warring government to make its people hate their opponents as it is for it to manufacture armaments. The animosity made in war-time by atrocity stories, Press propaganda, songs, and the rest is destroyed afterwards by reconciliation campaigns.

It was often remarked in the Great War, by soldiers returning from the trenches, that the people at home were far more bellicose than those at the front. While the propaganda songs in war-time (written mostly by those who had had no experience of battle) made the idea of going to war easier, the poems of experienced soldiers showed a real revulsion from war. Contrast, for example:

Good-bye-ee ! good-bye-ee
Wipe the tear, baby dear, from your eye-ee.
Tho' it's hard to part, I know,
I'll be tickled to death to go.
Don't cry-ee ! don't sigh-ee !
There's a silver lining in the sky-ee.
Bonsoir, old thing ! cheerio ! chin-chin !
Nah-poo !
Toodle-oo !
Good-bye-ee !

with Siegfried Sassoon's " Suicide in Trenches ":

I knew a simple soldier boy
Who grinned at life in empty joy,
Slept soundly through the lonesome dark,
And whistled early with the lark.

In winter trenches, cowed and glum
With crumps and lice and lack of rum,
He put a bullet through his brain.
No one spoke of him again.

* * *

You smug-faced crowds with kindling eye
Who cheer when soldier lads march by,
Sneak home and pray you'll never know
The hell where youth and laughter go.

The truth, in fact, is the opposite to proposition (1). It is difficult to make men go to war, and outside forces must be used to bring them to it. Men may be born capable of aggression, but they do not issue from the womb with rifles on their shoulders.

(2) The cause of war is even more commonly attributed to a second seemingly biological reason. It is said that, as the population of a country increases, the demands on the food-supply become too great to be met by the agriculture inside the national territory. The nation must therefore go to war to acquire adequate means of subsistence. This theory, which is a mixture of biological and economic ideas, is undoubtedly very widely held.

To scrutinise the " population pressure " theory of the cause of war, we must look at war more closely. Are all wars alike in character ? They are not. In Africa there are tribal wars for the purpose of slave-making; the Napoleonic Wars were wars among republics and monarchies; the Great War was a war between empires.

Is it true that imperial expansion, and ultimately war, is due to the pressure of " surplus population " at home ? From a study of the struggles of the French and German Empires during the last sixty years, we can see that expansion is not due to " population pressure." A country acquired colonial territory, in fact, usually when there was no " surplus " of population at home. Dr. Carr-Saunders points out:

" Between 1880 and 1900, France pursued a more deliberate and more vigorous expansionist policy than has been followed by any other country in the last hundred years. In West Africa, the Nile Valley, and the Far East she sought colonies, and successive French ministries continued to encourage the making of claims by explorers and officials on behalf of France. . . . [During this period] the French were acutely aware of the fact that, while the population of Germany was increasing rapidly, the population of France was almost stationary. . . .

" During the period preceding that in which Germany became industrialised . . . there were signs of over-population, for there was congestion in the rural areas and heavy emigration. But of expansionist sentiment there was no trace. As industrialisation became rapid the rate of population growth increased; [yet] signs of congestion vanished, and Germany became a country of immigration. Expansionist sentiment, however, made its appearance, and became very prominent; it would be possible to give numerous quotations from German authors in the earlier years of the present century who were demanding outlets for Germany's growing millions. . . . Since the War . . . though Germans fear depopulation and not over-population, they are again making expansionist claims and demanding colonies."[1]

It is said that, in 1913, the German population of the entire German colonial Empire was less than the German population of Paris.

The problem of war, therefore, is not one for the biologist, but for the economist, to explain. Theories that war is *caused* by " man's fighting instinct," by " racial " or " national antagonism," or by the " pressure of surplus population " are untrue. They are the stock-in-trade of propagandists. For example, it looks as though the leaders of the Nazis in Germany are trying to make the German people believe in waging a " tribal " war for agricultural land. They stint the people of fats and proteins and tell them they must fight for space.

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[1] *World Population.*

Incidentally they are trying, at the same time, to increase the birth-rate. In view of the misleading nature of the statements on war which have a biological flavour, it is the duty of biologists, maintaining a strict scientific attitude, to say that they have nothing important to tell the public about war: war is not a biological problem.

CHAPTER XIV

THE FUTURE OF BIOLOGY

As THE FLOWER is to the plant, so science is a working part as well as an ornament of society. Biology has grown up in the last hundred years as a structural element of the machinery of industrial civilisation. It grew as an agglomerate of various branches of study. Plant and animal breeders, collectors, agriculturists, chemists, doctors, and others tunnelled into the mountain of living creatures and met in the middle. After meeting, they branched out again into new galleries. It may be expected that biology will continue to develop under influences of the same general nature as those which affected its past. The scientists themselves are one factor.

Some scientists, whose number and quality in any future year cannot easily be estimated, possess scientific genius. But the main work of discovery is done, not by scientists of genius, but by highly competent research workers whose numbers depend on the numbers trained each year. It is generally agreed that biology becomes better and better supplied (relatively over-supplied at present) with trained men and women. Their training is getting stricter year by year, as the use of critical experimental methods saturates biological schools. If biology is to expand in the future, no check to its growth can be expected from a shortage of biologists.

There is no shortage, either, of biological problems that need solving. To-day's problems are the jumping-off points for the future. There are many obvious questions which the growth of the science has raised. There is the question of how the organisation centres, which control an individual's development, are related to the genes that make it resemble its parents. The organisation centres have been worked out in frogs, newts, and fowls. Genes have been especially studied in domestic plants, fruit-flies, fowls, and cattle. In the fowl, therefore, there is a possibility of these two branches of biology meeting. When this happens the marriage may be expected to be fertile.

The theory of the evolution of living forms has lately been subjected to mathematical treatment. The ideas coming from this treatment now need to be used in experiments and observations on living creatures in nature. A new, full, and strict natural history is growing up; it numbers the individuals of each species in a locality, takes account of the varieties of form within the species, studies the influence of the different species on each other, notes the effects of climatic and soil conditions, and thus discovers about the working of evolution through the selection of the most favourable types.

Biology is growing within itself in many other directions. The study of important chemicals, like those that cause fermentation, hormones, vitamins, drugs, substances that organise an embryo, and substances that induce cancer, is expanding all the time. Investigations of the nervous system have reached the point of throwing light on the operations of the mind. The knowledge of genes is weekly made more precise and extensive. But besides growing inside itself, biology is going to be affected by external influences.

The development of the sciences and techniques dealing with inanimate matter continually provides the biologist with new weapons. Two methods recently taken over from modern physics have been the use of X-rays, for analysing virus structure, and the use of energy-radiating phosphorus, for mapping the chemical movements in the bones of a living rat. Biologists have used improvements in the techniques of the cine-camera, the light-sensitive electric cell, and the wireless. The future of biology is going to be strongly influenced by the future of physics, chemistry, and engineering.

Finally, the ultimately decisive influence on the subject is that of society in general. In what directions will it demand knowledge? What resources will it provide for experiments? Science is a tool in the hand of mankind. Just as steel can be beaten either into a sword or a ploughshare, biology can be used either for man's fulfilment or for his destruction. Its future depends on the future of peace and on the future of production.

The following are some of the practical activities of modern biology:

(1) Carrying out chemical operations in the production of foodstuffs like yeast-extract, cheese, chocolate, etc.: preserving foodstuffs like fruit, eggs, and fish.

(2) Extracting vitamins from their natural sources: or manufacturing them. New ways of making Vitamin D are in use in America. Soviet scientists are extracting Vitamin C from the fruits, or hips, of the wild roses for the use of their Arctic settlers.

(3) Improving the natural clothing fibres like linen, cotton, silk, and wool. Research into the structure of wool, done in this country, has already yielded results of great general interest.

(4) Increasing the resistance of plants, animals, and men to disease.

(5) Improving the growth of farm plants and animals by controlling their surroundings and their internal states.

(6) Breeding high-yielding strains of plants after a careful study of the genes affecting each aspect of growth at each stage in the life of a plant. Promising studies on these lines are already being carried out in Holland.

(7) Destroying the dangerous insects, moulds, and other disease-carriers, pests, and parasites.

This book has attempted to interpret biology in terms of human life, and not to interpret humanity in terms of the lives of plants and animals. In the last part of this book it has been implied that, if biologists are to draw up the blinds on the lumber-room of the " social biology" of man, they must forget their usual biological views. Man uses tools, speaks, passes on traditions and makes inventions: inexact analogies with other species do not help us to understand his ways. It is in man's economic and social relations, not in his " animal nature," that a solution must be sought for problems like the decline in the birth-rate, unemployment, anti-Semitism, prostitution, and war.

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